



# SUSYGEN 2.2: A Monte Carlo Event Generator for MSSM Sparticle Production at $e^+e^-$ Colliders

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# SUSYGEN 2.2

## A Monte Carlo Event Generator for MSSM Sparticle Production at $e^+e^-$ Colliders

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Program classification: 11.1

### Abstract

SUSYGEN is a Monte Carlo program designed for computing distributions and generating events for MSSM sparticle production in  $e^+e^-$  collisions. The Supersymmetric (SUSY) mass spectrum may either be supplied by the user, or can alternatively be calculated in two different models of SUSY Breaking: gravity mediated supersymmetry breaking (SUGRA), and gauge mediated supersymmetry breaking (GMSB). The program incorporates the most important production processes and decay modes, including the full set of R-parity violating decays, and the decays to the gravitino in GMSB models. Initial state radiation corrections take into account  $p_T/p_L$  effects in the Structure Function formalism, and an optimised hadronisation interface to JETSET 7.4 including final state radiation is also provided.

To be submitted to Computer Physics Communications.

## NEW VERSION SUMMARY

*Title of new version:* SUSYGEN 2.2

*Catalogue number:*

*Program obtainable from:* CPC Program Library, Queen's University of Belfast, N. Ireland (see application form in this issue)

*Reference to original program:* SUSYGEN 1.0; S. Katsanevas and S. Melanchrinou, "SUSYGEN'', in the proceedings of the Workshop *Physics at LEP 2*, eds. G. Altarelli, T. Sjöstrand, and F. Zwirner, CERN 96-01, page 328, Geneva, 19 February 1996.

*Authors of original program:* Stavros Katsanevas, Stavros Melachroinos

*The new version supersedes the original program*

*Licensing provisions:* none

*Computer for which the new version is designed:*

DEC ALPHA, HP 9000/700, IBM AIX series;

*WWW site:* <http://lyohp5.in2p3.fr/delphi/katsan/susygen.html>

*Operating system under which the new version has been tested:* UNIX, VMS

*Programming language used in the new version:* FORTRAN 77

*Memory required to execute with typical data:*  $\approx 250 - 450\text{Kb}$

*No. of bits in a word:* 32

*No. of processors used:* 1

*The code has not been vectorised*

*Subprograms used:* CERNLIB [i], JETSET [ii], RANLUX [iii], PHOTOS [iv]

*No. of lines in distributed program, including test data, etc.:*  $\approx 18000$

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*Keywords:*  $e^+e^-$  collisions, LEP, Supersymmetry, SUSY, MSSM, R-parity violation, Supergravity, Gauge mediated Supersymmetry breaking

*Nature of physical problem*

The complexity and the interdependence of the MSSM signals demand a fast and precise simulation program which treats the production and decay of all possible sparticles in different models of supersymmetry breaking, and in models in which R-parity is either conserved or violated.

*Method of solution*

SUSYGEN 2.2 is a Monte Carlo generator for the tree-level production and decay of all MSSM sparticles at  $e^+e^-$  colliders. It includes pair-production of gauginos, sfermions and squarks, the production of a gravitino plus a neutralino in Gauge-mediated SUSY breaking models, the single production of gauginos through s-channel resonance in R-parity violating models, and the production of Higgses. The program implements all important decay modes of sparticles relevant to LEP energies, including

cascade decays to lighter SUSY states, radiative decays of gauginos to a photon, decays to the Higgses, decays to gravitinos, and R-parity violating decays to Standard Model particles. The precise matrix elements are used for the production and for the decay of sparticles, though helicity correlations are not taken into account. The mass spectrum of the SUSY particles at the electroweak scale is either calculated assuming a common mass scale at the GUT scale (Supergravity models or Gauge mediated SUSY breaking models), or the mass spectrum can be optionally provided by the user. The LSP can either be the neutralino, the sneutrino or the gravitino in R-parity conserving models, or there can be no LSP in the sense that all sparticles can decay to standard particles through R-Parity violation. The initial state radiative corrections take account of  $p_T/p_L$  effects in the Structure Function formalism. QED final state radiation is implemented using the PHOTOS library. An optimised hadronisation interface to JETSET 7.4 is provided, which also takes into account the lifetime of sparticles.

#### *Reasons for the new version*

SUSYGEN has been extensively used by the four LEP collaborations to simulate the expected signals on the way to the higher LEP energies. The scope of version 1.0 of the program was limited in the following way: only neutralino LSPs were implemented; gauge-mediated SUSY breaking scenarios, i.e. the production and decay of gravitinos was not implemented; no R-parity violation option was available; QED final state radiation was not included, and none of the Higgs production mechanisms were implemented.

#### *Restrictions on the complexity of the problem*

The factorised treatment of the production and decay of sparticles through the appropriate matrix elements is more accurate than the equivalent treatment of generators like e.g ISAJET [1] and SPYTHIA [2], where the sparticle decays are described by phase space. Nevertheless it is less accurate than programs which take helicity correlations into account, as for example is done in SUSY-GRACE (SUSY23) [3], or DFGT [4]. Squark hadronisation before decay is not implemented, and the hadronisation of squark decays via the R-parity violating coupling  $\lambda''$  is only simulated using the independent fragmentation scheme. The decays to gluinos are at present not implemented. And three-body decays of sfermions to lighter sfermions are not included.

*Typical running time:* 40 events/sec on a DEC ALPHA.

*Unusual features of the program:* none

#### *References*

- [i] CERN Program Library, CN Division, CERN, Geneva.
- [ii] T. Sjöstrand, Comp. Phys. Commun. **82** (1994) 74.
- [iii] F. James, Comput. Phys. Commun. **79** (1994) 111.
- [iv] E. Barberio and Z. Was, Comp. Phys. Commun. **79** (1994) 291.

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# LONG WRITE-UP

## 1 Introduction

In recent years supersymmetry (SUSY) has been extensively used to chart the map of possible physics beyond the standard model (SM). This symmetry predicts the existence of additional particles which differ from their standard model partners by half a unit of spin. The simplest model available is the Minimal Supersymmetric Standard Model (MSSM) [5, 6] which contains the minimal number of new particles and interactions that are consistent with the SM gauge group. In the MSSM all SM fermions have scalar SUSY partners (see Table 1): the sleptons, sneutrinos and squarks. The SUSY equivalent of the gauge and Higgs bosons are the charginos and neutralinos (the gauginos), which are the mass eigenstates of the  $(\tilde{W}^+, \tilde{H}^+)$  and  $(\tilde{\gamma}, \tilde{Z}, \tilde{H}_1^0, \tilde{H}_2^0)$  fields, respectively. Within the supersymmetric framework many theoretical questions of grand unified theories (GUTs) such as the hierarchy problem and the unification of couplings [7] may be successfully addressed.

particle		spin	sparticle		spin
quark	$q$	1/2	squarks	$\tilde{q}_{L,R}$	0
charged lepton	$l$	1/2	charged sleptons	$\tilde{l}_{L,R}$	0
neutrino	$\nu$	1/2	sneutrino	$\tilde{\nu}$	0
gluon	$g$	1	gluino	$\tilde{g}$	1/2
photon	$\gamma$	1	photino	$\tilde{\gamma}$	1/2
	$Z^0$	1	zino	$\tilde{Z}$	1/2
neutral higgses	$h, H, A$	0	neutral higgsinos	$\tilde{H}_{1,2}^0$	1/2
	$W^\pm$	1	wino	$\tilde{W}^\pm$	1/2
charged higgs	$H^\pm$	0	charged higgsino	$\tilde{H}^\pm$	1/2
graviton	$G$	2	gravitino	$\tilde{G}$	3/2
$\tilde{W}^\pm, \tilde{H}^\pm$ mix to form 2 chargino mass eigenstates $\chi_1^\pm, \chi_2^\pm$ $\tilde{\gamma}, \tilde{Z}, \tilde{H}_{1,2}^0$ mix to form 4 neutralino mass eigenstates $\chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0$ $\tilde{t}_L, \tilde{t}_R$ (and $\tilde{b}, \tilde{\tau}$ ) mix to form the mass eigenstates $\tilde{t}_1, \tilde{t}_2$					

Table 1: Particle-Sparticle correspondence in the MSSM

The masses and couplings of the new supersymmetric states are related by the symmetry to those of the SM states. If supersymmetry were an exact symmetry, the SUSY partners would be degenerate in mass with their SM partners. Since no such states have been observed to date, supersymmetry must be broken at some higher energy scale. Two supersymmetric breaking mechanisms have been studied in detail in the literature: gravity mediated supersymmetry breaking (SUGRA) [8, 9] and gauge mediated supersymmetry breaking (GMSB) [10, 11].

The first model (SUGRA) is inspired by supergravity theories, where supersymmetry is broken at some very high scale, a "hidden sector", close to the Grand Unification scale and is communicated to the visible sector through gravitational interactions. If one assumes universal soft breaking terms

at the GUT scale, the masses of the SUSY particles and their couplings can be calculated at the electroweak scale through the evolution of the renormalisation group equations (RGEs). The model thus predicts the entire SUSY spectrum from a few parameters.

Recently the second model (GMSB), where the supersymmetry breaking occurs at a relatively low scale (a few hundred TeV), has received considerable attention in the literature. Here the messengers of the supersymmetric breaking are the gauge bosons. This model also predicts mass relationships for the gauginos and the scalars, but the main difference to SUGRA models is that the  $\tilde{G}$  goldstino<sup>1</sup> – the longitudinal component of the gravitino – can be very light, and would thus be the Lightest Supersymmetric Particle (LSP).

Apart from the issue of supersymmetry breaking, a further complication arises when the SM is extended to incorporate SUSY. The most general interactions of the SM and SUSY particles invariant under the  $SU(3)_c \times SU(2)_L \times U(1)_Y$  gauge symmetry are those of the MSSM plus the additional superpotential terms [12]

$$W_{R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k. \quad (1)$$

Here  $L$  ( $Q$ ) are the lepton (quark) doublet superfields, and  $\bar{D}, \bar{U}$  ( $\bar{E}$ ) are the down-like and up-like quark (lepton) singlet superfields, respectively;  $\lambda, \lambda', \lambda''$  are Yukawa couplings, and  $i, j, k = 1, 2, 3$  are generation indices. The first two terms in Eq. (1) violate lepton number, while the last term violates baryon number. The simultaneous presence of the last two terms leads to rapid proton decay, and the solution of this problem in the MSSM is to exclude all terms in Eq. (1) by imposing the conservation of a discrete multiplicative quantum number, R-parity [13, 14], defined as:

$$R_p = (-1)^{3B+L+2S} \quad (2)$$

Here  $B$  denotes the baryon number,  $L$  the lepton number and  $S$  the spin of the particle state. However, this solution is not unique, and a number of models [15] predict only a subset of the terms in (1), thus protecting the proton from decay. These alternative solutions are denoted “R-parity violation”. Theoretically there is no clear preference for models which impose R-parity conservation or violation [14]. Experimentally the two cases correspond to vastly different signatures, as will be discussed below.

If R-parity is conserved one may expect two different classes of candidates for the LSP, depending on whether the messengers of the supersymmetry breaking are gravitational or the gauge bosons: the neutralino (or the sneutrino), or the gravitino. In either case the LSP is stable, a consequence of R-parity conservation. If the neutralino (or the sneutrino) is the LSP one expects events with large missing energy ( $\cancel{E}$ ) due to the neutralino escaping detection. In the second case where the gravitino is the LSP, the possible signatures depend on the decay rate of the heavier SUSY particles to the gravitino and on the nature of the NLSP (Next Lowest Supersymmetric Particle). For example, neutralino NLSPs decay to an undetectable gravitino and a photon, while sfermion NLSPs decay to the corresponding fermion and the gravitino. Prompt decays to the gravitino would produce the classical missing energy signatures, possibly with additional photons in the event; slow decays inside the detector volume may produce tracks with kinks or displaced vertices; and decays outside the detector may also produce heavy stable charged particle signatures if the NLSP is a charged particle.

R-parity violation has two mayor consequences for collider phenomenology. Firstly, the LSP is not stable and can decay to SM particles. And secondly, sparticles may be produced singly. This opens up a whole new area of different signatures, which in the simplest case may consist of acoplanar lepton pairs or acoplanar jets, or in the more complex case of multi-lepton and/or multi-jet final states, possibly with some missing energy.

---

<sup>1</sup>Throughout this paper we will refer to the  $\tilde{G}$  as the gravitino.



SUSYGEN 2.2 is a Monte Carlo generator capable of simulating the production and decay of all possible sparticles in the different scenarios described above, i.e. in models of different supersymmetry breaking (SUGRA or GMSB), and in models in which R-parity is either conserved or violated. SUSYGEN is dedicated to  $e^+e^-$  colliders<sup>2</sup> where it has been extensively used (and debugged!) by the four LEP collaborations. The program is based, for the most part, on the formalisms of [17] for the MSSM sparticle production and decays, on [18, 19] for SUGRA, on [20] for GMSB, and on [22, 23] for the  $\tilde{R}_p$  production and decays. It uses the precise matrix elements for the production and for the decay of sparticles, although helicity effects are not taken into account. SUSYGEN incorporates initial and final state radiative corrections, and includes a hadronisation interface to JETSET 7.4 [24].

The outline of this paper is as follows: after reviewing and defining the MSSM framework in Section 2, the physics content of the generator is described in Section 3. The structure of the program is outlined in Section 4, and instructions on how to obtain, compile and run the program are given in Section 5. Conclusions and future plans are given in Section 6. The Appendix lists the particle and production code conventions, the gaugino mass matrix basis, the formulas used for the production and the decay of sparticles, common blocks and the ntuple variables. Finally a test run input and output listing is given.

---

<sup>2</sup>The other three "general" SUSY programs are ISAJET [1], SPYTHIA [2] and SUSY-GRACE (SUSY23) [3]. They have different areas of speciality: ISAJET and SPYTHIA treat both hadronic and  $e^+e^-$  colliders, but they treat the sparticle decays through phase-space and they do not contain the full set of  $\tilde{R}_p$  decays, while SUSY-GRACE includes helicity correlations, but does not incorporate all SUSY processes. It has no  $\tilde{R}_p$  option yet. See also [16] and references therein for other generators or programs related to SUSY.

## 2 The MSSM framework

The MSSM is defined as the Supersymmetric extension of the SM which contains the minimal number of new particles and interactions that are consistent with the SM gauge group. The gauge couplings of the SUSY particles are equal to the SM gauge couplings. Experimental evidence shows that SUSY must be broken, and the masses of the superpartners are therefore much heavier than their SM counterparts. The exact nature of the Supersymmetry breaking mechanism is unknown, but it can be parameterised by the following soft supersymmetric breaking terms [25]:

- Gaugino masses:  $M_i \lambda_i$ , where  $i = 1, 2, 3$  for  $U(1), SU(2), SU(3)$  and  $\lambda_i$  denotes the gaugino partner of the corresponding gauge field.
- Higgsino masses:  $\mu \tilde{h}_1^0 \tilde{h}_2^0$  and  $\mu \tilde{h}_1^\pm \tilde{h}_2^\pm$ , where  $\mu$  is the higgsino mass mixing parameter.
- Scalar masses: *e.g.*  $m_{(\tilde{t}, \tilde{b})_L}^2 (\tilde{t}_L^* \tilde{t}_L + \tilde{b}_L^* \tilde{b}_L) + m_{\tilde{t}_R}^2 \tilde{t}_R^* \tilde{t}_R + m_{\tilde{b}_R}^2 \tilde{b}_R^* \tilde{b}_R$ , plus similar expressions for the first two generations and the sleptons and sneutrinos.
- ‘A’ Left-Right trilinear mixing terms: *e.g.*  $A_t \lambda_t (\tilde{t}_L H_2^0 - \tilde{b}_L H_2^+) \tilde{t}_R^*$ , plus similar expressions for  $A_b$  and  $A_\tau$ .

In the “unconstrained MSSM” the above mass terms are considered to be free parameters of the theory (Section 2.1). The large number of unknowns can be substantially reduced in “constrained versions of the MSSM” if a particular SUSY breaking mechanism is employed. Two such mechanisms are implemented in SUSYGEN, SUGRA and GMSB, and are discussed in Section 2.2. One of the most important aspects for collider phenomenology is the nature of the LSP, which determines the dominant decay modes of SUSY particles and hence their experimental signatures. This will be discussed in Section 2.3.

### 2.1 The unconstrained MSSM

The unconstrained MSSM corresponds in SUSYGEN to the following choices of the input card “MODES” (see also Section 5.1): MODES=2, MODES=4 or MODES=5.

#### 2.1.1 Gaugino Masses

There are four spin 1/2 SUSY partners to the colorless neutral gauge fields and higgs bosons, the neutral “gauginos”. Their interaction eigenstates may be written as [17]

$$\psi_l^0 = \left( -i\tilde{\gamma}, -i\tilde{Z}, \cos\beta\tilde{H}_1^0 - \sin\beta\tilde{H}_2^0, \sin\beta\tilde{H}_1^0 + \cos\beta\tilde{H}_2^0 \right), \quad (3)$$

where  $\tilde{\gamma}, \tilde{Z}, \tilde{H}_1^0, \tilde{H}_2^0$  denote the two component spinor fields of the photino, zino and the two neutral higgsinos, respectively;  $s_\theta$  and  $c_\theta$  are the weak angle sine and cosine; and  $\tan\beta = v_1/v_2$ , the ratio of the vacuum expectation values of the neutral Higgs fields. The mass matrix of the neutral gauginos is given by

$$M^0 = \begin{pmatrix} M_1 c_\theta^2 + M_2 s_\theta^2 & (M_2 - M_1) c_\theta s_\theta & 0 & 0 \\ (M_2 - M_1) c_\theta s_\theta & M_2 c_\theta^2 + M_1 s_\theta^2 & m_Z & 0 \\ 0 & m_Z & \mu \sin 2\beta & -\mu \cos 2\beta \\ 0 & 0 & -\mu \cos 2\beta & -\mu \sin 2\beta \end{pmatrix} \quad (4)$$

The physical mass eigenstates, the neutralinos ( $\chi_k^0$ ), are defined by

$$\chi_k^0 = N_{kl} \psi_l^0 \quad (5)$$

and the neutralino mass eigenvalues ( $m_{\chi_k^0}$ ) can be computed by diagonalising the mass matrix Eq. (4) according to

$$m_{\chi_k^0} \delta_{kl} = N_{km} N_{ln} M_{mn}^0. \quad (6)$$

There are two SUSY partners to the W gauge boson and the charged Higgs bosons. Their mass eigenstates are the charginos ( $\chi_k^+, \chi_k^-$ ), which are admixtures of their interaction eigenstates [17]

$$\begin{aligned} \psi_l^+ &= (-i\tilde{W}^+, \tilde{H}_2^+) \\ \psi_l^- &= (-i\tilde{W}^-, \tilde{H}_1^-). \end{aligned} \quad (7)$$

The chargino mass matrix is given by

$$M^c = \begin{pmatrix} M_2 & \sqrt{2}m_W \sin \beta \\ \sqrt{2}m_W \cos \beta & \mu \end{pmatrix} \quad (8)$$

and the chargino mass eigenstates are given by

$$\begin{aligned} \chi_k^+ &= V_{kl} \psi_l^+ \\ \chi_k^- &= U_{kl} \psi_l^- \end{aligned} \quad (9)$$

The chargino mass eigenvalues ( $m_{\chi_k^\pm}$ ) can be computed by diagonalising the mass matrix Eq. (8) according to

$$m_{\chi_k^\pm} \delta_{kl} = U_{km}^* V_{ln} M_{mn}^0. \quad (10)$$

The diagonalisation of the above two mass matrices gives four neutralino ( $\chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0$ ) and two chargino ( $\chi_1^\pm, \chi_2^\pm$ ) physical states. The masses and the couplings of these states are determined by the eigenvalues and the eigenvectors of Eq. (6,10). They depend on the three parameters ( $M_2, \tan \beta, \mu$ ) in the case of charginos, and on the four parameters ( $M_1, M_2, \tan \beta, \mu$ ) in the case of neutralinos. Appendix B gives more details on gaugino mixing and the different neutralino bases used inside SUSYGEN.

In order to simplify the parametric dependence a relationship between the gaugino masses is commonly assumed. In the simplest possible picture the gaugino masses  $M_1, M_2$  and  $M_3$  are assumed to be equal at the grand unification scale, an assumption which is natural in the context of gravity induced supersymmetry breaking. The one-loop renormalisation group equations then allow one to calculate the evolution of the three couplings to the EW scale. This determines the ‘‘GUT relations’’ for the gaugino mass terms [25]:

$$M_1 = \frac{5}{3} \tan^2 \theta_W M_2 \quad (11)$$

$$M_3 = \frac{\alpha_S}{\alpha_{EM}} \sin^2 \theta_W M_2 \quad (12)$$

Numerically this relationship (at the EW scale) is approximately given by  $M_3 : M_2 : M_1 \simeq 7 : 2 : 1$ . The above relationship obtained in the context of SUGRA models is also valid for GMSB models.

However, the existence of string models or other models with non-universal masses at the GUT scale [26] induces some scepticism on the general validity of Eq. (11,12). By default SUSYGEN uses Eq. (11), but the ratio  $M_2 : M_1$  may be optionally changed by the user.

The GUT relations ensure that the gluino (where  $m_{\tilde{g}} = M_3$ , neglecting QCD corrections) is normally much heavier than the SU(2) and U(1) gauginos. Their production is therefore typically inaccessible at LEP. However, in some models loop corrections to the gluino masses predict light gluinos [27]. And in GMSB models with two effective SUSY breaking scales, one for a colour-singlet and one for a colour non-singlet sector, gluinos may also be light, possibly even the LSP [28]. Light gluino scenarios are at present not implemented in SUSYGEN.

### 2.1.2 The Gravitino Mass

In GMSB models spontaneous SUSY breaking leads to a goldstone fermion, the goldstino  $\tilde{G}$  with very low mass. In local SUSY  $\tilde{G}$  is the longitudinal component of the gravitino. The  $\tilde{G}$  mass is determined by  $F$ , the characteristic scale of SUSY breaking, and is given by [25]:

$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_{Plank}} = 2.5 \times \left(\frac{\sqrt{F}}{100\text{TeV}}\right)^2 eV \quad (13)$$

For  $\sqrt{F} \sim 10^8$  TeV – the characteristic scale of string-motivated supergravity models – the  $\tilde{G}$  is fairly massive and has no consequences for LEP phenomenology. In gauge mediated models  $\sqrt{F} \sim 100\text{--}2000$  TeV, and the  $\tilde{G}$  is the LSP. Note that the scale  $\sqrt{F}$  also determines the coupling strength of the gravitino and thus enters in the neutralino-gravitino production cross section, and in the decay rate of the lifetime of the NLSP, which can only decay to the gravitino if R-parity is conserved.

### 2.1.3 Third Generation Sfermion Masses and Mixing Angles

The SUSY partners of the SM fermions are the sleptons  $\tilde{l}_L, \tilde{l}_R$ , the sneutrinos  $\tilde{\nu}$  and the squarks  $\tilde{q}_L, \tilde{q}_R$ . The charged leptons and the quarks have two SUSY partners, one for each lepton/quark chirality. The third generation sfermions ( $\tilde{t}, \tilde{b}, \tilde{\tau}$ ) are the most likely candidates for the lightest scalar quark or lepton states because of the potential for large mixing angles between the left and right handed states, and because of the large third generation Yukawa couplings. This may be seen from the stop and sbottom mass matrices [29]

$$\begin{pmatrix} \tilde{t}_L & \tilde{t}_R \end{pmatrix} \begin{pmatrix} m_{\tilde{t}_L}^2 + m_t^2 + m_D^2 & m_t X_t \\ m_t X_t & m_{\tilde{t}_R}^2 + m_t^2 + m_D^2 \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix} \\ \begin{pmatrix} \tilde{b}_L & \tilde{b}_R \end{pmatrix} \begin{pmatrix} m_{\tilde{b}_L}^2 + m_b^2 + m_D^2 & m_b X_b \\ m_b X_b & m_{\tilde{b}_R}^2 + m_b^2 + m_D^2 \end{pmatrix} \begin{pmatrix} \tilde{b}_L \\ \tilde{b}_R \end{pmatrix} \quad (14)$$

from which the mass eigenstates of the stop ( $\tilde{t}_1, \tilde{t}_2$ ) and the sbottom ( $\tilde{b}_1, \tilde{b}_2$ ) can be obtained by diagonalisation. Here

$$X_t = A_t - \mu \cot \beta \quad (15)$$

$$X_b = A_b - \mu \tan \beta \quad (16)$$

$$m_D^2 = (I^3 - Q \sin^2 \theta_W) |\cos 2\beta| m_Z^2 \quad (17)$$

where  $m_D$  are the so-called “D-terms”,  $I^3$  is the third component of isospin, and  $Q$  is the electric charge. Note that for stops and sbottoms the off-diagonal terms in Eq. (14) are sizeable and lead to appreciable mixing between the left-right states. This is not the case for the first two squark generations, where the analogous  $m_q X_q$  terms are small since  $m_q \sim 0$ . Depending on  $\tan \beta$  either the stop or the sbottom can be the lightest squark state. A similar argument applies for the stau, which can be lighter than the selectron and the smuon due to mixing.

SUSYGEN implements mixing between the left-right third generation sfermions, and the user can control the amount of mixing through the parameters  $A_t, A_b, A_\tau$ . In the unconstrained MSSM (MODES=2,4) the user may alternatively provide the explicit mixing angles  $\theta_{\tilde{t}}, \theta_{\tilde{b}}, \theta_{\tilde{\tau}}$  which parameterise the mass-eigenstates in terms of the left-right states:

$$\begin{aligned} \tilde{f}_1 &= \tilde{f}_L \cos \theta_{\tilde{f}} + \tilde{f}_R \sin \theta_{\tilde{f}} \\ \tilde{f}_2 &= -\tilde{f}_L \sin \theta_{\tilde{f}} + \tilde{f}_R \cos \theta_{\tilde{f}} \end{aligned} \quad (18)$$

### 2.1.4 The Higgs Mass

The tree level Higgs masses only depend on two parameters:  $m_A$ , the mass of the CP-odd Higgs and  $\tan\beta$ . The radiative corrections [30] modify these predictions and introduce a dependence on the rest of the supersymmetric mass spectrum. The RGE improved formulae [19] implemented in SUSYGEN take into account most of these corrections. The Higgs masses show a strong dependence on the mixing of the stop  $X_t$ , increasing the theoretical upper limit on the Higgs mass for larger values of  $X_t$ .

## 2.2 The constrained MSSM

The constrained MSSM corresponds in SUSYGEN to the following choices of the input card “MODES” (see also Section 5.1): MODES=1 or MODES=3.

### 2.2.1 Mass Spectrum in SUGRA models

In Supergravity inspired models the soft SUSY breaking parameters are assumed to be universal at the GUT scale, reducing the number of parameters to:

- $m_0$ , the common mass of the sfermions at the GUT scale.
- $M_2$ , the SU(2) gaugino mass.
- $\mu$ , the mass mixing parameter of the Higgs doublets.
- $\tan\beta$ , the ratio of the vacuum expectation values of the two Higgs doublets.
- $A_t, A_b, A_\tau$ , the trilinear couplings in the Higgs sector.

All above parameters are defined at the EW scale except for  $m_0$ , which is defined at the GUT scale<sup>3</sup>. The sfermion masses  $m_0$  are evolved from the GUT scale to the EW scale according to the formulae given in Appendix B of reference [18]. Mixing of the third generation sfermions is taken into account according to Eq. (14) through the parameters  $A_t, A_b$  and  $A_\tau$ . For certain sets of parameters the sfermion masses at the EW scale may turn out negative, and in this case a warning is issued and the program skips this particular parameter point. The Gaugino and the Higgs mass spectra are calculated as discussed in Sections 2.1.1, 2.1.4.

For the first two generations, and neglecting the D-terms Eq. (17), the renormalisation of the scalar masses at e.g.  $\tan\beta = 1$  give

$$(\tilde{m}_R^2 - m_0^2) : (\tilde{m}_L^2 - m_0^2) : (m_{\tilde{q}}^2 - m_0^2) : M_2 = 0.22 : 0.75 : 6.40 : 1 \quad (19)$$

displaying a clear mass hierarchy, with the right sleptons ( $\tilde{m}_R$ ) being the lightest states, followed by a mass degenerate left slepton doublet ( $\tilde{m}_L$ ), and the first and second generation squarks at higher masses.

Radiative corrections to the soft SUSY breaking terms can induce electroweak symmetry breaking, resulting in further constraints on the parameters of SUGRA models. This is at present not implemented within SUSYGEN, although private versions of SUSYGEN interfaced to the code of [31] exist, and may be obtained from the authors.

### 2.2.2 Mass Spectrum in GMSB models

In GMSB models the scalar mass relationships are [25]:

$$m_{\tilde{q}}^2 : \tilde{m}_L^2 : \tilde{m}_R^2 : M1 = 11.6 : 2.5 : 1.1 : \sqrt{N_{5,10}} \quad (20)$$

---

<sup>3</sup>Note that for example the ISAJET program [1] defines the above parameters at the GUT scale.

Here  $N_{5,10}$  is a number characterising the number of representations in the messenger sector. Note that the squarks are in principle very heavy in GMSB models. The gravitino is the LSP, and its mass is given by Eq. (13). For  $N_{5,10} = 1$  the neutralino is the NLSP, while for  $N_{5,10} \geq 2$  the  $\tilde{l}_R$  is the NLSP. The Gaugino and the Higgs mass spectra are calculated in the same way as in the SUGRA model. The following parameters determine the entire mass spectrum of the model:  $N_{5,10}$ ,  $\mu$ ,  $M_2$ ,  $\tan\beta$ ,  $A_t$ ,  $A_b$ ,  $A_\tau$ .

### 2.3 The Nature of the LSP and the Sparticle Decay Modes

SM particles have  $R_p = +1$  while their SUSY partners have  $R_p = -1$ , which can easily be seen from Eq. (2). The multiplicative conservation of R-parity only allows vertices with an even number of SUSY particles, and the LSP is therefore stable if R-parity is conserved. Cosmological arguments [32] then require the LSP to be neutral, and the following R-parity conserving LSP candidates are implemented in SUSYGEN: the lightest neutralino, the sneutrino or the gravitino. The LSP is unstable and can decay to SM particles if R-parity is broken, and the above cosmological arguments do not apply. In this case the lightest chargino, the sleptons or the third generation squarks are also good LSP candidates. Gluino LSPs are at present not implemented in SUSYGEN.

Note that only a subset of the LSP candidates may be realised in constrained versions of the MSSM. In SUGRA models the lightest neutralino is the most likely LSP candidate, while in GMSB models the gravitino is the LSP.

All sparticle decay modes relevant to LEP phenomenology are implemented with the exception of the three body decays of sfermions to lighter sfermions (which are only important in very specific regions of parameter space, see for example [33, 34]), and the decays to gluinos. Cascade decays to intermediate sparticle states are also fully taken into account.

SUSYGEN simulates the following set of R-parity conserving decay modes:

- Three body decays of gauginos to lighter gauginos, e.g.  $\chi^+ \rightarrow f f' \chi^0$ .
- Two body decays of gauginos to sfermions, e.g.  $\chi^+ \rightarrow l^+ \tilde{\nu}$ .
- Two body decays of gauginos to the Higgs, e.g.  $\chi_k^0 \rightarrow H \chi_i^0$ .
- Radiative two body decays of neutralinos to a photon and a lighter neutralino, e.g.  $\chi_k^0 \rightarrow \gamma \chi_i^0$ .
- Two body decays of charginos to neutralinos, e.g.  $\chi^+ \rightarrow W^+ \chi^0$ .
- Two body decays of sfermions to gauginos, e.g.  $\tilde{f} \rightarrow f \chi$ .
- Two body decays to the gravitino, e.g.  $\chi^0 \rightarrow \gamma \tilde{G}$ .

The R-parity violating superpotential Eq. (1) contains the 45 additional Yukawa couplings  $\lambda_{ijk}$ ,  $\lambda'_{ijk}$ ,  $\lambda''_{ijk}$ . The  $LL\bar{E}$  term corresponding to  $\lambda_{ijk}$  is antisymmetric in  $i, j$ , and we take  $i < j$ . The  $\bar{U}\bar{D}\bar{D}$  term ( $\lambda''_{ijk}$ ) is antisymmetric in  $j, k$ , therefore  $j < k$ . To avoid fast proton decay and evade other low energy constraints only a subset of the 45 couplings can be non-zero. It is usually assumed that the  $\lambda$ -couplings display a strong hierarchy [14], in which case it is often sufficient to consider only one non-zero coupling, as is done in SUSYGEN. The following set of R-parity violating decays are included in SUSYGEN for the three operators  $LL\bar{E}$ ,  $LQ\bar{D}$  and  $\bar{U}\bar{D}\bar{D}$  and a single non-zero  $\mathcal{R}_p$  coupling:

- Three body decays of gauginos to SM particles, e.g.  $\chi^0 \rightarrow l^+ l^- \nu$  for  $\lambda_{ijk} \neq 0$ .
- Two body decays of sfermions to SM particles, e.g.  $\tilde{l}^+ \rightarrow l^+ \nu$  for  $\lambda_{ijk} \neq 0$ .

### 3 Physics content

This section provides an overview of the physics content of the generator. The implemented SUSY production mechanisms are described in Section 3.1, and the sparticle decays in Section 3.2. The implementation of initial and final state radiative corrections are discussed in Section 3.3, and sparticle lifetime and the hadronisation interface to JETSET are described in Sections 3.4 and 3.5.

#### 3.1 Sparticle Production

The production mechanisms and their corresponding SUSYGEN process numbers are summarised in Table 4 in the Appendix. The diagrams for the s- and t-channel production of charginos and neutralinos (SUSYGEN processes 1-13) are shown in Fig. 1. For large sneutrino and slepton masses the s-channel diagram dominates, while for small sneutrino (slepton) masses the t-channel contributions can be large, resulting in destructive (constructive) interference for chargino (neutralino) production [17]. The cross sections therefore depend on the chargino and neutralino masses and their couplings (and hence on  $M_1, M_2, \mu$  and  $\tan \beta$ ) as well as on the selectron and electron sneutrino masses.

Sfermions are produced in pairs (processes 14-35) through  $\gamma, Z$  exchange in the s-channel. The  $\tilde{\nu}_e$  and  $\tilde{e}$  are also produced with chargino and neutralino exchange in the t-channel [17]. Fig. 2 shows the relevant diagrams. The sfermion cross sections depend on the sfermion masses, and on the chargino or the neutralino masses and couplings in the case of electron-sneutrino and selectron pair production, respectively. For the third generation sfermions ( $\tilde{\tau}, \tilde{t}$  and  $\tilde{b}$ ) the left and right sfermion states can mix, and the cross sections also depend on the mixing angle  $\theta_{\tilde{f}}$  [29].

In GMSB models single (processes 37-39) or double gravitino (not implemented in SUSYGEN) production becomes accessible at LEP [20]. The corresponding feynman diagrams are shown in Fig. 3.

In R-parity violating models sneutrinos can be produced singly via the  $LL\bar{E}$  coupling at LEP, either in s-channel resonance [35], or in  $\gamma e$  collisions [36]. At present only the resonant production of sneutrinos (processes 40-45) (with non-zero couplings  $\lambda_{121}, \lambda_{131}$ ) and their subsequent decays to  $\chi_i^\pm l^\mp$  or  $\chi_i^0 \tilde{\nu}$  are implemented. The corresponding feynman diagrams are shown in Fig. 4.

Finally the 5 Higgs production processes ( $hZ, HZ, hA, HA, H^+H^-$ ) are also provided through an interface to PYTHIA. Here the RGE improved masses and mixings of Section 2.1.4 are used. This is the less developed part of the program, and we suggest that more specialised programs (e.g. see [16]) are used for dedicated Higgs studies.

In summary the 50 production processes contained in SUSYGEN are the following:

$$e^+e^- \rightarrow \left\{ \begin{array}{l} \chi_i \chi_j \\ \chi_i^\pm \chi_j^\mp \\ \tilde{f} \tilde{f} \\ \chi_i \tilde{G} \\ \chi_i^\pm l^\mp \\ \chi_i^0 \nu \\ hZ, HZ, hA, HA, H^+H^- \end{array} \right. \quad (21)$$

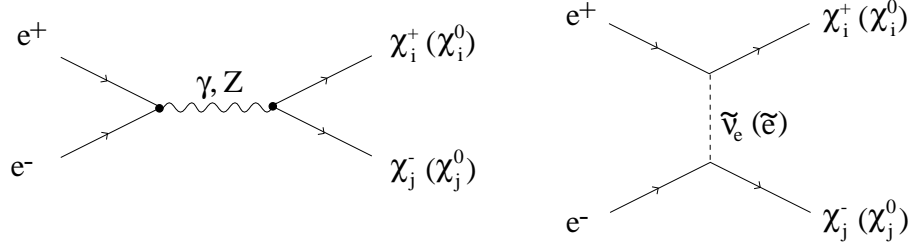


Figure 1: Chargino/neutralino production.

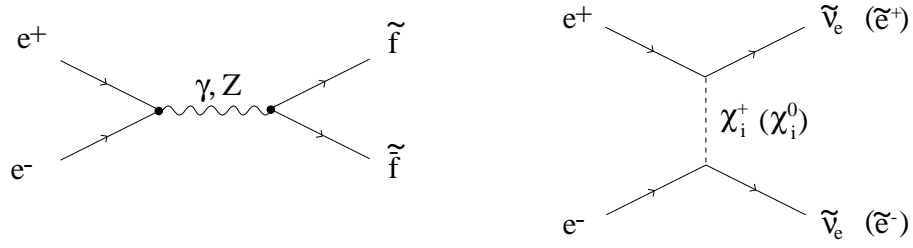


Figure 2: Sfermion production.

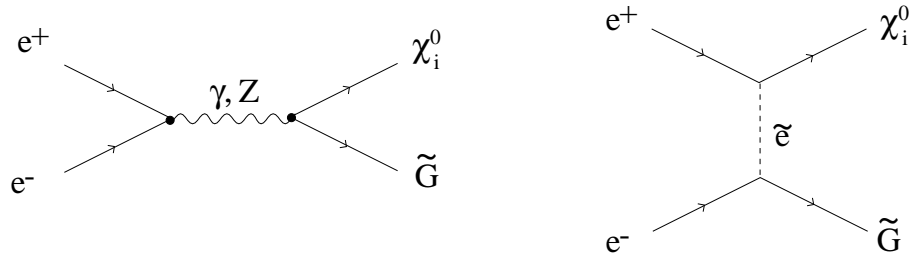


Figure 3: Single gravitino production.

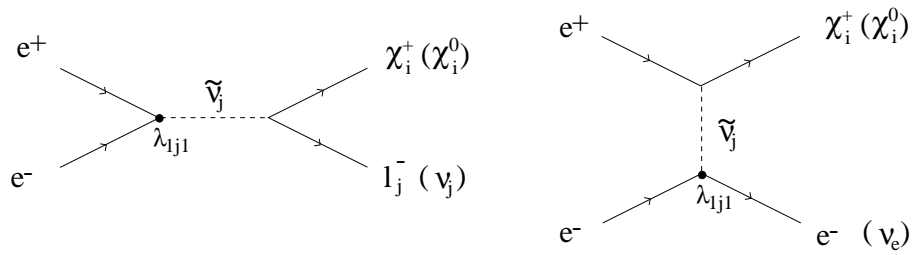


Figure 4: Sneutrino resonance production.



## 3.2 Sparticle decays

Sparticles can decay in two modes: In the  $R_p$  conserving mode sparticles decay to lighter sparticles and SM particles (Sections 3.2.1,3.2.2). In the  $R_p$  violating mode sparticles can additionally decay to SM particles only (Sections 3.2.3,3.2.4).

### 3.2.1 $R_p$ Conserving Gaugino Decay Modes

The charginos  $\chi_n^+$  and the higher mass neutralinos  $\tilde{\chi}_k^0$  ( $k=2,3,4$ ) can decay to the three-body final states [17]:

$$\begin{aligned}\chi_n^+ &\rightarrow \begin{cases} \chi_m^0 l^+ \nu, \chi_m^0 q \bar{q}', \\ \chi_m^+ l^+ l^-, \chi_m^+ q \bar{q}, \chi_m^+ \nu \bar{\nu} \end{cases} \\ \chi_k^0 &\rightarrow \begin{cases} \chi_m^0 l^+ l^-, \chi_m^0 q \bar{q}, \chi_m^0 \nu \bar{\nu} \\ \chi_m^\pm l^\mp \bar{\nu}, \chi_m^\pm q \bar{q}' \end{cases}\end{aligned}\tag{22}$$

Fig. 5 and 6 show the feynman diagrams for the decays of Eq. (22). One can in general distinguish between two regimes: In the first the scalar masses are much larger than the gaugino mass, and the decays occur through the  $s$ -channel to off-shell gauge bosons and the lighter gauginos, e.g the  $W^* \chi^0$ ,  $Z^* \chi^+$  channels in the case of the chargino decays and the  $W^* \chi^+$ ,  $Z^* \chi^0$  in the case of the neutralino decays. In this case the different branching ratios are mostly determined from the decays of the off-shell  $W^*$  and  $Z^*$ . In the second regime the sfermions have masses close to or below the gauginos, and the  $u, t$ -channels with  $\tilde{l}^*$ ,  $\tilde{\nu}^*$  or  $\tilde{q}^*$  exchange dominate and enhance the branching ratios to the corresponding fermions. Particular care has been taken to take into account the masses of the final fermions, so that e.g scenarios where one has "quasi-degenerate" chargino and neutralino masses [37] give the correct branching ratios and kinematics.

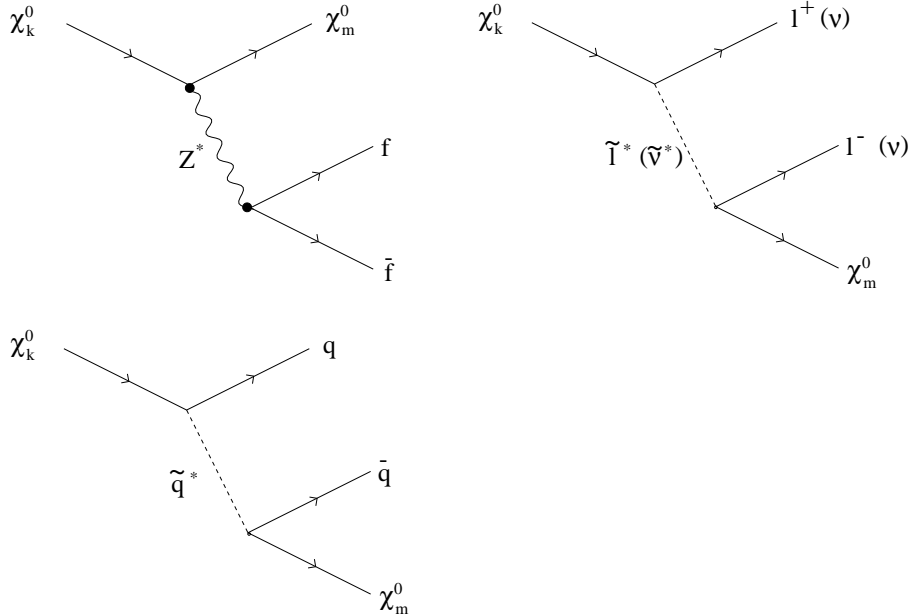


Figure 5:  $R_p$  conserving neutralino three body decays.

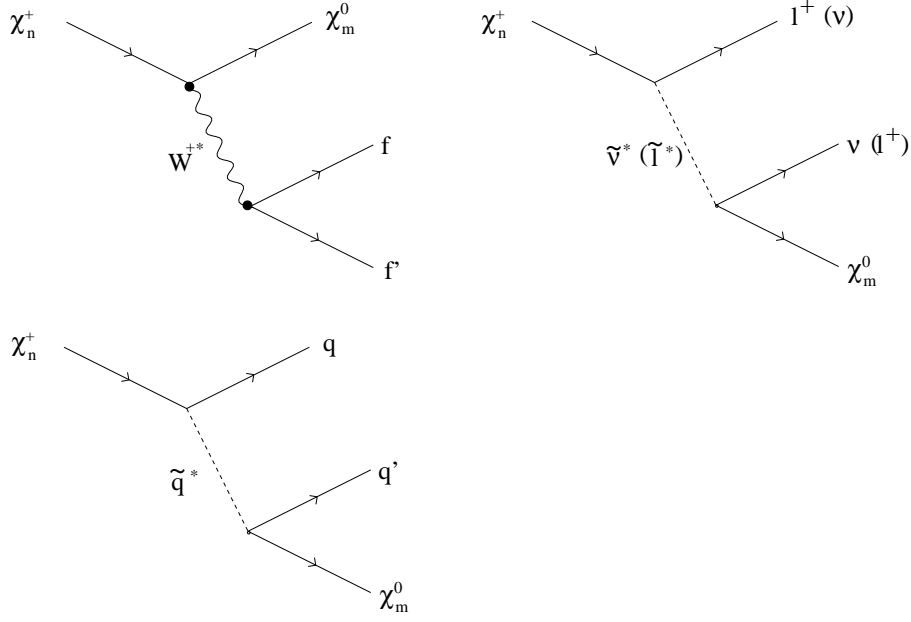


Figure 6:  $R_p$  conserving chargino three body decays.

If the sfermion mass is below the gaugino mass, two-body decays of the gauginos to the sfermions become dominant decay modes. This is implemented in SUSYGEN in two ways: In the first mode – which corresponds to the input card “TWOB FALSE”, see section 5.1 – no distinction between three-body and two-body decays of gauginos is made. Instead the three-body calculation is used, and the pole at  $p_{\tilde{f}}^2 = M_{\tilde{f}}^2$  is avoided by the inclusion of the sfermion width in the propagator<sup>4</sup>. Above threshold the propagator term forces the two-body kinematics, and the three-body decay is therefore equivalent to two two-body decays. In the second mode – corresponding to the card “TWOB TRUE” – the two-body gaugino decays are calculated explicitly. The following two-body decays are implemented:

$$\chi_n^+ \rightarrow \begin{cases} \tilde{f} f' \\ W^+ \chi_m^0 \end{cases} \quad (23)$$

$$\chi_n^0 \rightarrow \tilde{f} f$$

In addition to the decay modes of Eq. (22)-(23) the gauginos can either decay to the Higgs [38], or in restricted regions of parameter space radiatively via one loop diagrams [18] to  $\chi_1^0 \gamma$ . The radiative decays are particularly important in the supersymmetric limit  $\tan(\beta) \rightarrow 1$ ;  $M, \mu \rightarrow 0$ , where they are dominant.

$$\chi_k^0 \rightarrow \begin{cases} \chi_m^0 H^0, \chi_m^0 h, \chi_m^0 A \\ \chi_m^0 \gamma \end{cases} \quad (24)$$

$$\chi_n^+ \rightarrow \chi_m^0 H^+$$

<sup>4</sup>The propagator term  $D = (p_{\tilde{f}}^2 - M_{\tilde{f}}^2)^{-1}$  is replaced by  $D = (p_{\tilde{f}}^2 - M_{\tilde{f}}^2 + iG_{\tilde{f}})^{-1}$ , where  $G_{\tilde{f}} = \Gamma_{\tilde{f}} M_{\tilde{f}}$ .

In GMSB models the gravitino is the LSP, and the gauginos can decay to [21]

$$\begin{aligned}\chi_n^0 &\rightarrow \left\{ \tilde{G}\gamma, \tilde{G}Z, \tilde{G}H^0, \tilde{G}h, \tilde{G}A \right. \\ \chi_m^+ &\rightarrow \left\{ \tilde{G}W, \tilde{G}H^+ \right.\end{aligned}\tag{25}$$

The coupling of the gravitino can be very small, and thus the decay  $\chi_1^0 \rightarrow \tilde{G}\gamma$  is phenomenologically the most interesting mode if it occurs inside the detector. An isotropic two body decay has been assumed.

### 3.2.2 $R_p$ Conserving Sfermion Decay Modes

The sfermion decays to a gaugino and a fermion can also be separated into two cases. In the first case the lightest neutralino ( $\chi_1^0$ ) is the only gaugino lighter than the sfermion, and the typical decay mode is

$$\tilde{f} \rightarrow f\chi_1^0\tag{26}$$

with the exception of the stop, where the decay  $\tilde{t} \rightarrow t\chi_1^0$  is kinematically inaccessible at LEP and therefore proceeds through the Cabbibo suppressed mode  $\tilde{t} \rightarrow c\chi_1^0$ . In the second case heavier neutralinos  $\chi_k^0$  ( $k = 2, 3, 4$ ) or charginos  $\chi_n^+$  may be lighter than the sfermion, and the sfermion decays through a cascade of gauginos:

$$\begin{aligned}\tilde{l}(\tilde{\nu}) &\rightarrow \left\{ \begin{array}{l} l(\nu)\chi_k^0 \\ \nu(l)\chi_n^+ \end{array} \right. \\ \tilde{q} &\rightarrow \left\{ \begin{array}{l} q\chi_k^0 \\ q'\chi_n^+ \end{array} \right.\end{aligned}\tag{27}$$

In GMSB models decays to gravitinos are also possible [21], although in practice only the decay of the NLSP to the gravitino is of importance. The implemented decays are:

$$\tilde{f} \rightarrow \tilde{G}f\tag{28}$$

The above decays cover neutralino and gravitino LSP scenarios. If the sneutrino is the LSP (or other sfermions are the LSP in  $R_p$  violating models), sleptons and squarks can also decay via virtual  $W^*, Z^*, \chi^{+*}$  and  $\chi^0*$  exchange to the sneutrino. At present these decay modes are not implemented in SUSYGEN.

### 3.2.3 $R_p$ violating Gaugino Decay Modes

SUSYGEN implements decays for a single non-zero R-parity violating coupling  $\lambda_{ijk}$ ,  $\lambda'_{ijk}$  or  $\lambda''_{ijk}$ , where  $i, j, k$  are generation indices, and the three couplings correspond to the  $LL\bar{E}$ ,  $LQ\bar{D}$  or  $\bar{U}\bar{D}\bar{D}$  operators in Eq. (1). Neutralinos can decay to [22]:

$$\chi_n^0(LL\bar{E}) \rightarrow \left\{ l_i^- \bar{\nu}_j l_k^+, l_i^+ \nu_j l_k^-, \bar{\nu}_i l_j^- l_k^+, \nu_i l_j^+ l_k^- \right.\tag{29}$$

$$\chi_n^0(LQ\bar{D}) \rightarrow \left\{ l_i^- u_j \bar{d}_k, l_i^+ \bar{u}_j d_k, \nu_i d_j \bar{d}_k, \bar{\nu}_i \bar{d}_j d_k \right.\tag{30}$$

$$\chi_n^0(\bar{U}\bar{D}\bar{D}) \rightarrow \left\{ u_i d_j d_k, \bar{u}_i \bar{d}_j \bar{d}_k \right.\tag{31}$$

and Fig. 7 show the corresponding diagrams (for example) for the  $LQ\bar{D}$  operator. Charginos can decay to [22]:

$$\chi_n^+(LL\bar{E}) \rightarrow \left\{ \nu_i \nu_j e_k^+, e_i^+ e_j^+ e_k^-, e_i^+ \nu_j \nu_k, \nu_i e_j^+ \nu_k \right. \quad (32)$$

$$\chi_n^+(LQ\bar{D}) \rightarrow \left\{ \nu_i u_j \bar{d}_k, l_i^+ \bar{d}_j d_k, l_i^+ \bar{u}_j u_k, \bar{\nu}_i \bar{d}_j u_k \right. \quad (33)$$

$$\chi_n^+(\bar{U}\bar{D}\bar{D}) \rightarrow \left\{ \bar{d}_i \bar{d}_j \bar{d}_k, u_i u_j d_k, u_i d_j u_k \right. \quad (34)$$

The above decays are particularly relevant when the chargino is the LSP. Charginos will normally decay to the neutralino via Eq. (22) if the neutralino is the LSP, in which case the decays of Eq. (32)-(34) only dominate for large couplings  $\lambda$  and when the exchanged sfermion mass is close to the mass of the chargino.

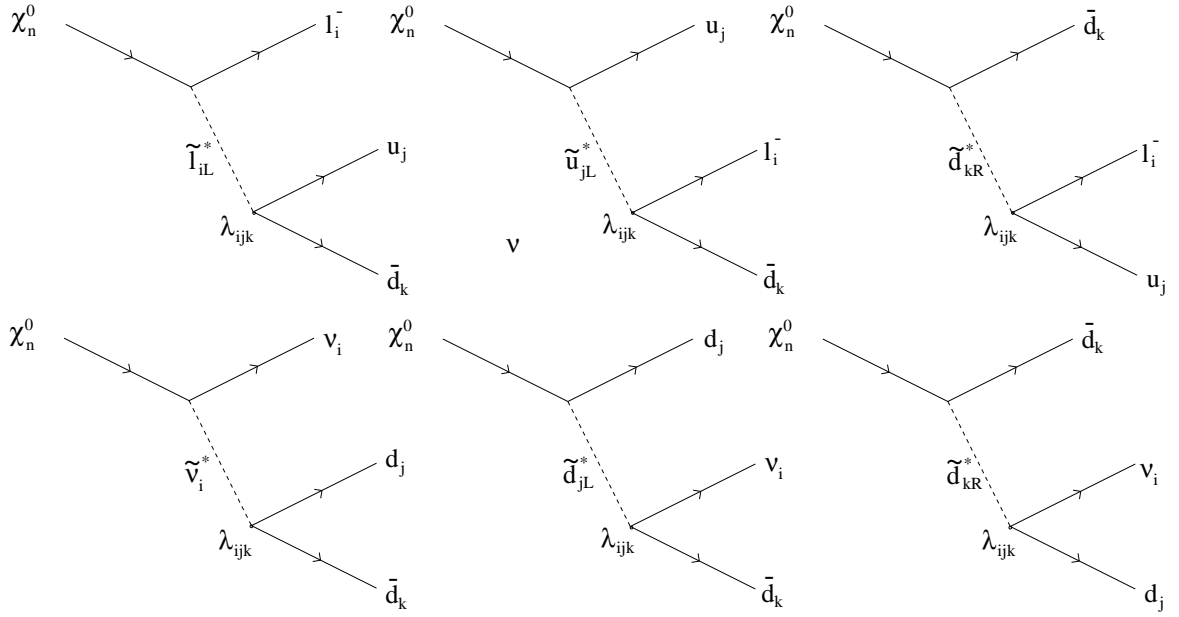


Figure 7: R-parity violating neutralino decays for a dominant  $LQ\bar{D}$  operator.

### 3.2.4 $R_p$ violating Sfermion Decay Modes

Sfermions can decay directly to SM particles through a dominant  $LL\bar{E}$  coupling via

$$\begin{aligned} \tilde{l}_{iL}^- &\rightarrow \nu_j l_k^- \\ \tilde{l}_{jL}^- &\rightarrow \nu_i l_k^- \\ \tilde{l}_{kR}^- &\rightarrow \nu_i l_j^-, \nu_j l_i^- \\ \tilde{\nu}_i &\rightarrow l_j^- l_k^+ \\ \tilde{\nu}_j &\rightarrow l_i^- l_k^+ \end{aligned} \quad (35)$$

where  $\tilde{l}_{iL}$  denotes a left-handed slepton of generation  $i$ . For a dominant  $LQ\bar{D}$  operator sfermions decay via

$$\tilde{l}_{iL}^- \rightarrow \bar{u}_j d_k$$

$$\begin{aligned}
\tilde{\nu}_{iL} &\rightarrow d_j \bar{d}_k \\
\tilde{u}_{jL} &\rightarrow l_i^+ d_k \\
\tilde{d}_{jL} &\rightarrow l_i^- u_k \\
\tilde{d}_{kR} &\rightarrow l_i^- u_j \\
\tilde{d}_{kR} &\rightarrow \bar{\nu}_i d_j
\end{aligned}
\tag{36}$$

and similarly for a dominant  $\bar{U}\bar{D}\bar{D}$  operator

$$\begin{aligned}
\tilde{u}_{iR} &\rightarrow \bar{d}_j \bar{d}_k \\
\tilde{d}_{jR} &\rightarrow \bar{u}_i \bar{d}_k \\
\tilde{d}_{kR} &\rightarrow \bar{u}_i \bar{d}_j.
\end{aligned}
\tag{37}$$

Note that SUSYGEN takes into account mixing between the left-right third generation sfermion states. As already mentioned in Section 3.2.2, three-body decays of sfermions to lighter sfermions are not included in SUSYGEN. These decays are only of importance if the produced sfermion is the NLSP which cannot decay directly via a specific  $R_p$  violating coupling, and the LSP is another sfermion.

### 3.3 Initial and Final State radiative corrections

The initial state corrections are implemented using a factorised "radiator formula" (REMT by Kleiss) where exponentiation of higher orders and a  $P_T$  dependent distribution have been implemented [39]. They have been checked against other initial state codes and found to agree at the percent level, once the prescriptions of the scales e.t.c were made to agree.

Final state radiative corrections are implemented within SUSYGEN in two ways: Firstly QED and QCD corrections to quark final states are treated by JETSET (through a LUSHOW call) in the hadronisation interface (see also section below). QED Bremsstrahlung off leptons is implemented using the PHOTOS package [40]. This allows an estimate of Bremsstrahlung effects in the leading-logarithmic approximation up to  $O(\alpha^2)$ , including double emission of photons.

### 3.4 Lifetime

SUSYGEN calculates the lifetime of the sparticles from their decay rate, and implements secondary vertices for long-lived particles accordingly. The lifetime information is important for the  $R_p$  violating LSP decays when the coupling strength  $\lambda$  is small, and for the GMSB decays to the gravitino. The inclusion of lifetime effects can be optionally turned off.

### 3.5 Hadronisation

SUSYGEN is fully interfaced to JETSET 7.4 [24] which takes care of the hadronisation of quarks. Here we describe the details of the interface and the hadronisation models used by SUSYGEN.

Two fragmentation schemes can be chosen by the card *FRAG* (see also section 5.1). In the independent fragmentation (IF) scheme the final state quarks are treated as independent particles with respect to each other. There is no QCD radiation between the final state quarks, and the hadronisation process produces relatively hard jets. Clearly this is an unphysical simplification, and the IF scheme should only be used to compare and evaluate the effect of gluon radiation. In the second scheme (the default) the final state quarks are evolved according to the Lund Parton Shower model. A colour string is formed between colour singlet  $q\bar{q}$  states, and the two quarks are subsequently evolved in time/space, emitting gluon radiation between the two quarks. The jets are much softer owing to the gluon radiation between the quark states, which produces additional soft particles.

In the simplest case when there are only two final state quarks (for example in the process  $e^+e^- \rightarrow \tilde{b}\tilde{b} \rightarrow \chi^0 b \chi^0 \bar{b}$ ) there is no ambiguity in the colour string assignment. In the case when quarks are produced by colourless sparticles a colour string is formed between each of the decay products of the colourless states. For example in the process  $e^+e^- \rightarrow \chi^+\chi^- \rightarrow (\chi^0 q_1 q_2)(\tilde{\chi}^0 q_3 q_4)$  a colour string is formed between the quarks  $q_1 q_2$  and another one between the quarks  $q_3 q_4$ .

A further complication arises when the  $R_p$  violating couplings  $\lambda''$  produce triple quark final states (for example in the decay  $\tilde{\chi}^0 \rightarrow q_1 q_2 q_3$ ). The triple quark vertices are not implemented in the higher level user interface of JETSET, but are supported by the lower level JETSET routines. Here we use a prescription kindly provided by Torbjørn Sjostrand [41] to implement this type of vertex: The two quarks  $q_1 q_2$  are connected by a double T-junction to a diquark of flavour  $(q_1, q_2)$  with zero momentum and the third quark  $q_3$ . JETSET subsequently treats the parton shower evolution of the three quarks correctly, but produces the error messages

```
Advisory warning type 2 given after      1 LUEXEC calls:
(LUPREP:) unphysical flavour combination
```

which should be ignored.

At present the JETSET hadronisation interface described above has two limitations: Firstly if squarks decay via the  $R_p$  violating coupling  $\lambda''$  to two quarks ( $\tilde{q}_1 \rightarrow q_2 q_3$ ) the colour string connection between  $q_2 q_3$  is not supported by JETSET, and we have to resort to the independent fragmentation scheme instead. Secondly, because the lifetime of the decay  $\tilde{t} \rightarrow \chi^0 c$  is larger than the hadronisation scale, stops should hadronise (to stop mesons) prior to their decay. Stop meson hadronisation is not implemented in SUSYGEN.

## 4 Program description

The SUSYGEN program may be used in two different ways. Firstly as a standard MC program to generate MC events for one particular set of input SUSY parameters. And secondly to scan SUSY parameter space in  $M_2, \mu, \tan \beta$  and  $m_0$ , where SUSYGEN calculates the masses, cross sections and decay branching ratios for each point, and also optionally generates weighted signal events for each of the specified SUSY processes. In the “SCAN” mode the calculated SUSY parameters can also be written to an ntuple, which can be subsequently analysed by the user.

The user has the option to directly access the LUND common block within the program in the routine USER. This is particularly useful for feasibility studies in the SCAN mode, where one might for example estimate detection efficiencies by applying a simple set of cuts inside the above routine. The calculated efficiencies are stored in the ntuple, one efficiency value for each of the generated SUSY signals. An example USER routine which selects hadronic events with large missing  $E_T$  is provided with the release version of SUSYGEN.

In the following the structure of the program and the main subroutines are described. A description of the common blocks is given in Appendix D. Inputs and Outputs of the program are described in sections 5.1,5.2. The program is divided into four stages. The first stage performs general initialisations:

- reads the input cards in subroutine SCARDS using the CERN package FFREAD. The user can define his/her own cards in subroutine USER.SCARDS.
- then books histograms in routine SBOOK and calls NTUPLE\_INIT to define the SUSYGEN ntuple.
- initialises the sparticle names in SUPART and calls the routine USER\_INIT for any other user-dependent initialisation.

The second stage uses the input information to calculate the masses, mixings, branching ratios and cross sections<sup>5</sup>. The routine SUSINI calls further subroutines:

- SUSANA for the calculation of the masses/mixings of the sparticles. The routine SUSANA calls the routines:
  - SFERMION, which determines the sfermion masses either using the routine SMGUT, which computes the masses of the sfermions in the SUGRA model or the GMSB model, or simply by taking each sfermion mass from the input cards. The user can provide the mixings parameters of the third generation sfermions through input cards, or alternatively the sfermion mixing is calculated in this routine according to Eq. (14,18).
  - GAUGINO, which computes the gaugino masses and mixing through the diagonalisation of the corresponding matrices  $M^0, M^c$ .
  - SUBH, which computes the Higgs masses; and PINTERF, which passes the Higgs parameters to PYTHIA.
  - LEPLIM, which examines whether the specific point has already been excluded by LEP I searches. The imposition of this constraint is selected through input cards and should be developed by the user.
  - RPARINI, which initialises the calculations of the  $\mathcal{R}_p$  diagrams and decay branching ratios.
- BRANCH for the determination of the widths and branching ratios of the sfermion and gaugino decays.

---

<sup>5</sup>SUSYGEN can operate in SCAN mode, where a range of input values is scanned (see input cards section). In this mode SUSYGEN loops over the input parameter range and recalculates the second stage parameters for each parameter space point.

- First the  $R_p$ -conserving two body decay widths of sfermions and gauginos are calculated.
- Routine WICONST calculates the 3-body decay constants and the function WSC calculates the partial decay rates.
- Routines NTONPH and NTOXH calculate the gaugino decays to a photon or a Higgs.
- In routine INTERF the widths of the 3 previous steps are stored in the common block SSMODE. The nomenclature of ISAJET 7.03 [1] has been retained for comparison purposes. Then the gauge mediated and  $R_p$  decays are calculated and stored in the same common block in the routines MGMDECAY and RPARDECAY, respectively. Finally the total sparticle widths and branching ratios are determined by summing up the partial decay rates in routine SSNORM.
- The total cross sections are calculated in the routines CHARGI-HIGINIT (see table 2). The initial state radiation corrections are calculated in routine REMT1, and routine PROCINIT stores the cross sections and other information for each of the 50 processes in the common blocks PROC1, PROC2.

Production mechanism	Total cross section Routine name	Differential cross section ( $d\sigma/dt$ ) Routine name
$\chi_i^+ \chi_j^-$	CHARGI	GENCHAR
$\chi_i^0 \chi_j^0$	PHOTI	GENPHO
$\tilde{e}\tilde{e}$	-	GENSEL
$\tilde{e}_L \tilde{e}_R$	-	GENSELRS
$\tilde{\mu}\tilde{\mu}, \tilde{\tau}\tilde{\tau}, \tilde{q}\tilde{q}$	-	GENSMUS
$\tilde{\nu}_e \tilde{\nu}_e$	-	GENSNUE
$\tilde{\nu}\tilde{\nu}$	-	GENSNU
$\tilde{G}\chi_i^0$	-	GENPHOG
$\nu\chi_i^0$	-	RPVZINT
$l^\pm \chi_i^\pm$	-	RPVWINT
$hZ, HZ, H^+ H^-,$	HIGINIT	PYTHIA
$HA, hA$	HIGINIT + SIGHA	PYTHIA

Table 2: Subroutine names of the total and differential cross-sections.

In the third stage “weighted” MC events are generated, i.e. one of the selected production processes is chosen with a probability proportional to its relative cross section. The routine SUSEVE then loads the corresponding variables from the commons PROC1, PROC2 and performs the following tasks:

- Picks a value for  $\cos \theta$  distributed according to the differential cross section ( $d\sigma/dt$ ) for the process (see also table 2) and creates the 4-vectors for the final states of the hard process.
- The decay channel is determined in the routine DECABR from the branching ratios of the sparticles, and the two-body or three-body decay 4-vectors are calculated in the routines SMBOD2 and SMBOD3, respectively. In SMBOD3 the differential decay rate  $d\Gamma/dsdt$  is sampled in  $s$  and  $t$ , and the angular distributions of the decay products determined accordingly.
- The decay products from the previous step are presented again to DECABR and decayed, until no more unstable SUSY particles are left.
- The routines REMT3 and FINRAD\_PHOTOS perform the adjustments due to initial and final state radiation.



- The above 4-vectors are interfaced to LUND in the subroutine SFRAGMENT where they fragment, hadronise and decay.

While still in the third stage, inside the event loop, the routines USER\_WRITE and USER are called where the user has the options to write an event out and/or analyse it directly by accessing the LUND common LUJETS.

At the end of the event loop – while still inside the SCAN loop – the calculated parameters (masses, BRs, cross-sections) and the rough detection efficiencies calculated in the routine USER are stored in an ntuple by the routine NTUPLE\_FILL.

In the fourth stage the routines SUSEND and USER\_END perform general and user-specific closing functions.

## 5 Setting up and running SUSYGEN

The program is supplied as a single Fortran file which can be compiled using standard FORTRAN77. The release version may be obtained from the CPC Program Library, and the most recent version can be obtained from <http://lyohp5.in2p3.fr/delphi/katsan/susygen.html>. The program has to be linked to the standard CERNLIBs, the JETSET7.4 library, PYTHIA and PHOTOS. This may be done by the following set of commands on UNIX:

```
f77 -g -w -static -c susygen.f
f77 -o susygen.exe susygen.o /cern/pro/lib/libphotos.a \
/cern/pro/lib/libjetset74.a 'cernlib mathlib packlib shift'
```

and on VMS:

```
$ for/optimize/nodebug susygen
$ cernlib jetset74,photos,packlib,genlib,kernlib
$ link/nodeb susygen,'lib$'
```

To run the program one has to give appropriate input cards, which in the example below are assumed to be in the file `susygen.cards`. To run SUSYGEN on UNIX:

```
susygen.exe < susygen.cards > susygen.log
```

and on VMS:

```
$ define/user sys$input susygen.cards
$ define/user sys$output susygen.log
$ run/nodeb susygen
```

The Inputs and Outputs are discussed in the following.

### 5.1 Input

The input to SUSYGEN consists of a single text file, the cards file, described below. Alternatively a very advanced graphics X-interface, `Xsusy`, is also available for UNIX machines. The `Xsusy` interface allows input from pop-up menus rather than a cards file, and is extremely user friendly. The SUSYGEN output may be analysed with PAW and/or `emacs` within `Xsusy`. Fig. 8 shows a typical `Xsusy`-session. `Xsusy` is not part of the standard CPC distribution of SUSYGEN, but may be obtained from <http://lyohp5.in2p3.fr/delphi/katsan/susygen.html>.

In the absence of any of the cards the default values given below are chosen.

#### 5.1.1 Set masses and mixings

**MODES 1** MODES determines which input parameters will be used to determine the supersymmetric masses and mixings:

- MODES=1 the gaugino/higgsino and sfermion spectrum is calculated using the values  $M$ ,  $\mu$ ,  $m_0$ ,  $\tan\beta$ , and  $A$  as input for the case of SUGRA models, and  $M$ ,  $\mu$ ,  $\tan\beta$  and  $A$  for GMSB models.
- MODES=2 the gaugino/higgsino spectrum is calculated using the values  $M$ ,  $\mu$ ,  $m_0$  and  $\tan\beta$  as input, while the the sfermion masses are taken from the input cards below.

- MODES=3 the gaugino/higgsino spectrum is calculated using the values  $M$ ,  $\mu$ ,  $m_0$  and  $\tan \beta$ , but the "gaugino mass relationship" does not relate  $M_1$  to  $M_2$  anymore, their relationship is set by the card RS below. The sfermion values are given according to the hierarchy proposed for MODES=1.
- MODES=4 the gaugino/higgsino spectrum is calculated using the values  $M$ ,  $\mu$ ,  $m_0$  and  $\tan \beta$ , but the "gaugino mass relationship" does not relate  $M_1$  to  $M_2$  anymore, their relationship is set by the card RS below, while the sfermion values are taken from the input cards below.
- MODES=5 TO BE USED WITH CARE.  $M$  below is the requested mass of the lightest neutralino. A corresponding  $M_2$  may not exist for the given set of parameters, or very often double solutions are possible (e.g for positive  $\mu$  and low  $\tan \beta$ ).

**M** 90. (  $M_2$  the SU(2) gaugino mass in GeV, at the EW scale)

**mu** 90. ( $\mu$  in GeV, at the EW scale)

**m0** 90. ( $m_0$  in GeV, a common scalar mass at the GUT scale)

**tanb** 4.0 ( $\tan \beta = v_2/v_1$ , at the weak scale)

**A** 0. 0. 0. ( $A_t, A_b, A_\tau$  soft SUSY breaking trilinear couplings)

**RS** 1. RS is the gauge mass unification breaking scale defined as  $M_1 = M_2 \frac{5 \sin^2 \theta_W}{3 \cos^2 \theta_W} RS$

**MA** 500. (The mass of the A Higgs in GeV)

**MIX** 0 If set to 1, permits sfermion mixing.

**C** — **ARE RELEVANT FOR MODES 2 and 4**

**MSQUARK** 1000. (the mass of  $\tilde{q}, m_{\tilde{q}}$ )

**MLSTOP** 1000. (the mass of  $\tilde{t}_L, m_{\tilde{t}_L}$ )

**MRSTOP** 1000. (the mass of  $\tilde{t}_R, m_{\tilde{t}_R}$ )

**MLSEL** 1000. (the mass of  $\tilde{e}_L, m_{\tilde{e}_L}$ )

**MRSEL** 1000. (the mass of  $\tilde{e}_R, m_{\tilde{e}_R}$ )

**MSNU** 1000. (the mass of  $\tilde{\nu}, m_{\tilde{\nu}}$ )

**MASMX** 0. 0. 0. 0. 0. 0. When different from 0. sets the mass of  $\tilde{t}_1, \tilde{b}_1, \tilde{\tau}_1, \tilde{t}_2, \tilde{b}_2, \tilde{\tau}_2$  respectively.

**PHIMX** 0. 0. 0. sets mixing angle between  $\tilde{t}_1$ - $\tilde{t}_2$ ,  $\tilde{b}_1$ - $\tilde{b}_2$  and  $\tilde{\tau}_1$ - $\tilde{\tau}_2$ .

### 5.1.2 Set production processes

**ZINO** FALSE (all pairs of  $\chi^0$ )

**WINO** FALSE (all pairs of  $\chi^\pm$ )

**SELECTRON** FALSE (all pairs of  $\tilde{e}$ )

**SMUON** FALSE (all pairs of  $\tilde{\mu}$ )

**STAU** FALSE (all pairs of  $\tilde{\tau}$ )

**SNU** FALSE (all pairs of  $\tilde{\nu}$ )

**SSTOP** FALSE (all pairs of  $\tilde{t}$ )

**SBOTTOM** FALSE (all pairs of  $\tilde{b}$ )

**SQUARK** FALSE (all pairs of  $\tilde{q}$  other than  $\tilde{t}, \tilde{b}$ )

**HIGGS** FALSE (all higgses a la PYTHIA)

**GRAVITINO** FALSE ( $\tilde{G}\chi^0$ , when MGM is true)

**RSINGLE** FALSE ( $\nu\chi^0$  and  $\mu\chi^\pm$  or  $\tau\chi^\pm$  through  $\tilde{\nu}$  resonance when RPARITY is FALSE)

**PROCSEL** 0 0 0 0 0 0 0 0 0 0

Possibility to choose to produce any 10 processes. The first word is the number of processes to be selected and the next ten give the process number (see process table in the text). The corresponding generic card is turned TRUE. That is e.g ZINO is set to TRUE when one sets PROCSEL 1 2, asking to produce only the process  $\chi_1^0\chi_2^0$ .

**DECSEL** 1

Determines the modes of decay of virtual Z and W. The first 4 determine whether the virtual  $Z^*$  can decay to  $u\bar{u}$ ,  $d\bar{d}$ ,  $\nu\bar{\nu}$ ,  $e^+e^-$  and the next two the decays of  $W^*$  to  $u\bar{d}$  or  $e^+\nu$ . The next 12 determine the decays to the two other families. The last 5 determine whether one wants to turn on/off the decays to  $\chi_i\gamma$ ,  $\chi_i h$ ,  $\chi_i H$ ,  $\chi_i A$ ,  $\chi_i^\pm H^\mp$ .

### 5.1.3 Gauge mediated SUSY models

**MGM** FALSE Switches on Production ( $\chi\tilde{G}$ ) of gravitinos and the decay modes to the gravitino in models of gauge mediated supersymmetry breaking.

**LSUSY** 500. Supersymmetry Breaking Scale  $\sqrt{F}$  (in GeV) (gauge mediated SUSY models)

### 5.1.4 $R_p$ violating SUSY models

**RPARITY** TRUE Is  $R_p$  conserved?

**INDIC** o i j k  $R_p$  violating coupling indices of the single dominant coupling  $\lambda_{ijk}$ . The operators o=1,2,3 correspond to the  $R_p$  violating operators  $LL\bar{E}$ ,  $LQ\bar{D}$ ,  $\bar{U}\bar{U}\bar{D}$  respectively.

**LAMDA** 0.1 Strength of the  $R_p$  violating coupling  $\lambda_{ijk}$ .

**TWOB** FALSE Switch on/off explicit calculation of the gaugino two-body decays. The TWOB is automatically set to true if  $R_p$  is violated.

### 5.1.5 Generation conditions

**ECM** 183. (Center of mass energy).

**SUSEVENTS** 100. (Total number of events to be produced. If more than one processes are possible, they will be produced in percentages corresponding to their respective cross-sections).

**ISR** 1 (Permit or not (0) initial state radiation).

**FSR** 1 (Permit or not (0) final state radiation).

**GENER** 0 (Generate events(1) or not (0)).

**LIFE** TRUE (Include effects of finite lifetime of sparticles).

**FRAG** 1 (Fragmentation scheme. Normal string type fragmentation (1) or independent fragmentation (2)).

**LCUT** 200. (Decay length cut in cm, thereafter particles considered stable).

### 5.1.6 Control switches

**DEBUG** 0 (Print additional debug information. The higher the value, the more information is printed ( $0 < \text{Debug} < 31$ )).

**LUWRIT** FALSE (Write out events to FOR012.dat or not) .

**SCAN** FALSE (Scan the values in  $M$  and  $\mu$ ).

**ISCAN** 0 0 0 0 (Number of scan values in  $M_2$ ,  $\mu$ ,  $m_0$  and  $\tan\beta$ ). There is also the following option: setting the relevant ISCAN value to -1, the program takes the first corresponding value VSCx as a starting value, the second as ending value and the third as the step.

**VSC1** 0 (List of scan values in  $M_2$ , up to 10, or start, end, step values)

**VSC2** 0 (List of scan values in  $\mu$ , up to 10, or start, end, step values)

**VSC3** 0 (List of scan values in  $m_0$ , up to 10, or start, end, step values)

**VSC4** 0 (List of scan values in  $\tan\beta$ , up to 10, or start, end, step values)

**LEPI** FALSE (Impose LEPI constraints or not).

## 5.2 Output

Four output files are produced by SUSYGEN:

- The file susygen.dat, which lists the sparticle masses, cross sections, branching ratios and decay modes.
- The file susygen.his. The ntuple with ID 200 in this file contains the calculated masses, cross sections and BRs.
- The fortran file UNIT 12, e.g. “fort.12” on UNIX or “FOR012.DAT” on VMS, which contains the LUND common of the generated events. See routine SXWRLU in the program for more information on the output format of this file.
- The file susygen.log, which contains warning and error messages and a LUND listing of the generated events (if the debug level is set to “DEBUG n”, where  $n > 0$ ).

Ntuple 200 is a column-wise Ntuple, and contains one entry per SCAN loop (SUSYGEN can scan parameter space in  $\mu, M_2, \tan\beta, m_0$ ). The ntuple variables are summarised in Tables 11-22 in the Appendix.

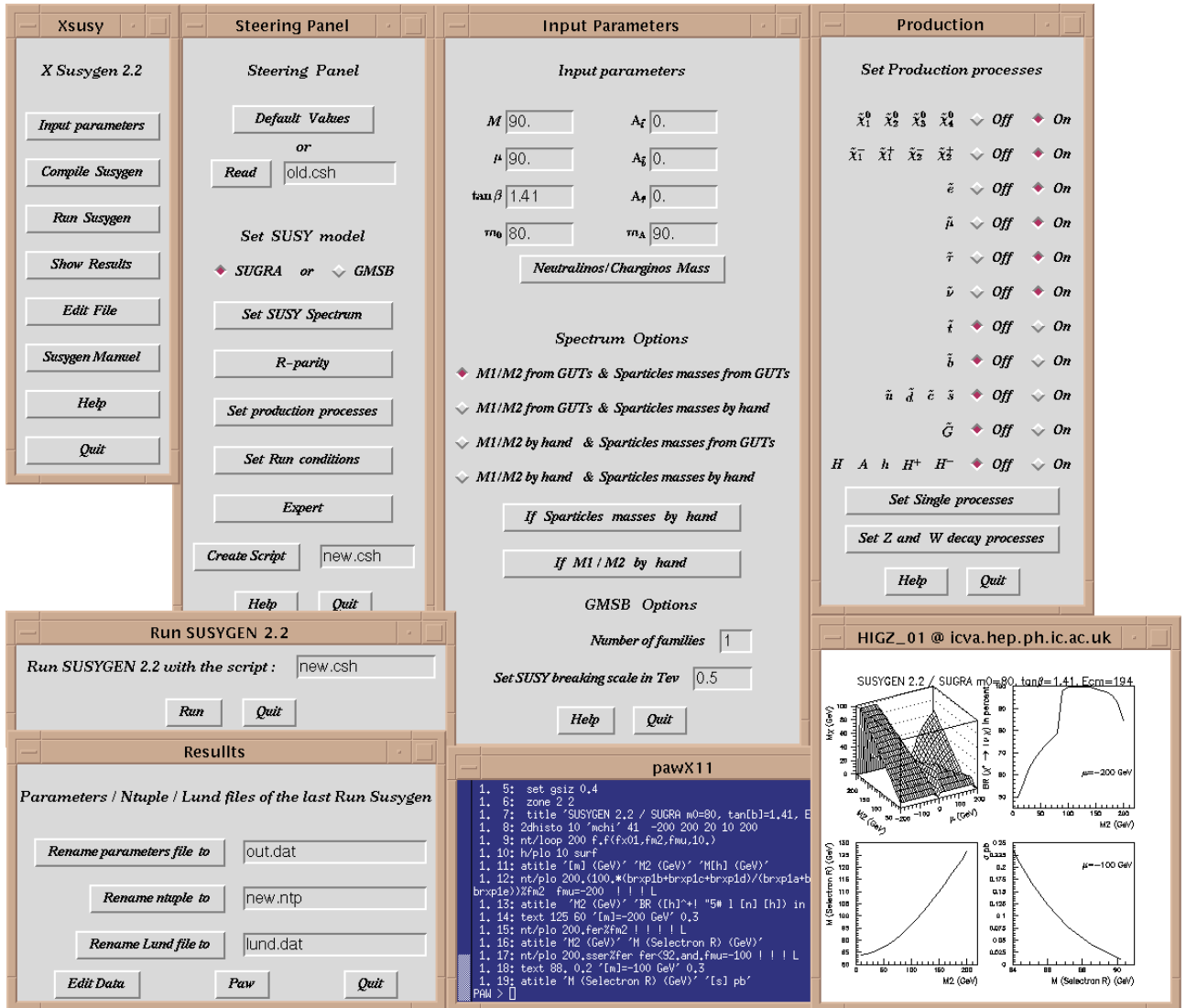


Figure 8: The graphical user interface Xsusy.

## 6 Conclusions and Future plans

SUSYGEN 2.2 is a fast and versatile Monte-Carlo generator that has profited from the collective experience of the four LEP collaborations. Its current precision is sufficient for detailed studies at LEP. It permits the study of gravity and gauge mediated models of SUSY breaking in models in which R-parity is either conserved or violated. A total of 50 production processes are included, which are the most important processes in the models studied above. SUSYGEN is extremely user friendly and the code is transparent. It is maintained in CMZ, and private developments can easily be incorporated in the main body of the generator.

There are a few things the authors would like to incorporate in the next version:

- Extend SUSYGEN to hadron and  $ep$  colliders.
- Treatment of helicity correlations. This development is well under way and should be implemented in a few months.
- Include a light gluino scenario.
- Include single squark/sneutrino production in  $R_p$  processes where a radiated photon from one of the incoming leptons interacts with the opposite lepton through a "resolved" quark or lepton component.
- Include three body decays of sfermions to lighter sfermions.
- First order corrections to SUSY masses and cross-sections. This development could be important in particularly difficult areas of the parameter space (e.g.  $\tan\beta = 1$  see [45]), where corrections of the order 20% are possible.

Other more long-range plans include:

- A more precise Higgs treatment, which also includes Higgs decays to SUSY particles.
- Incorporation of cosmological constraints and other constraining measurements (e.g.  $b \rightarrow s\gamma$  constraints) at an informative level.

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# APPENDIX

## A Codes for particles and processes

Table 3 lists the LUND KF codes which SUSYGEN assigns the sparticles in the LUND record. Note that *SusyProd* stands for the production process of the sparticles, upper case  $\tilde{G}$  is the Gravitino and lower case  $\tilde{g}$  is the gluino. Table 4 lists the SUSY production process code conventions.

LUND KF id	Sparticle	LUND KF id	Sparticle
41	$\tilde{d}_L$	61	$\tilde{b}_R$
42	$\tilde{u}_L$	62	$\tilde{t}_R$
43	$\tilde{s}_L$	63	$\tilde{b}_1$
44	$\tilde{c}_L$	64	$\tilde{t}_1$
45	$\tilde{b}_L$	65	$\tilde{\tau}_1$
46	$\tilde{t}_L$	66	$\tilde{b}_2$
47	$\tilde{d}_R$	67	$\tilde{t}_2$
48	$\tilde{u}_R$	68	$\tilde{\tau}_2$
49	$\tilde{s}_R$	69	$\tilde{G}$
50	$\tilde{c}_R$	70	$\tilde{g}$
51	$\tilde{e}_L^-$	71	$\chi_1^0$
52	$\tilde{\nu}_e$	72	$\chi_2^0$
53	$\tilde{\mu}_L^-$	73	$\chi_3^0$
54	$\tilde{\nu}_\mu$	74	$\chi_4^0$
55	$\tilde{\tau}_L^-$	75	$\chi_1^+$
56	$\tilde{\nu}_\tau$	76	$\chi_2^+$
57	$\tilde{e}_R^-$	77	$\chi_1^-$
58	$\tilde{\mu}_R^-$	78	$\chi_2^-$
59	$\tilde{\tau}_R^-$	79	SusyProd

Table 3: LUND KF labels and particle codes (K(I,2) in the lund common).

Process id	Process	Process id	Process
1	$\chi_1^0 \chi_1^0$	26	$\tilde{t}_1 \tilde{t}_1$
2	$\chi_1^0 \chi_2^0$	27	$\tilde{t}_2 \tilde{t}_2$
3	$\chi_2^0 \chi_2^0$	28	$\tilde{u}_L \tilde{u}_L$
4	$\chi_1^0 \chi_3^0$	29	$\tilde{u}_R \tilde{u}_R$
5	$\chi_2^0 \chi_3^0$	30	$\tilde{d}_L \tilde{d}_L$
6	$\chi_3^0 \chi_3^0$	31	$\tilde{d}_R \tilde{d}_R$
7	$\chi_1^0 \chi_4^0$	32	$\tilde{c}_L \tilde{c}_L$
8	$\chi_2^0 \chi_4^0$	33	$\tilde{c}_R \tilde{c}_R$
9	$\chi_3^0 \chi_4^0$	34	$\tilde{s}_L \tilde{s}_L$
10	$\chi_4^0 \chi_4^0$	35	$\tilde{s}_R \tilde{s}_R$
11	$\chi_1^+ \chi_1^-$	36	$\chi_1^0 \tilde{G}$
12	$\chi_1^+ \chi_2^-$	37	$\chi_2^0 \tilde{G}$
13	$\chi_2^+ \chi_2^-$	38	$\chi_3^0 \tilde{G}$
14	$\tilde{\nu}_e \tilde{\nu}_e$	39	$\chi_4^0 \tilde{G}$
15	$\tilde{\nu}_\mu \tilde{\nu}_\mu$	40	$\chi_1^0 \nu$
16	$\tilde{\nu}_\tau \tilde{\nu}_\tau$	41	$\chi_2^0 \nu$
17	$\tilde{e}_L \tilde{e}_L$	42	$\chi_3^0 \nu$
18	$\tilde{e}_R \tilde{e}_R$	43	$\chi_4^0 \nu$
19	$\tilde{e}_L \tilde{e}_R$	44	$\chi_1^+ \lambda^-$
20	$\tilde{\mu}_L \tilde{\mu}_L$	45	$\chi_2^+ \lambda^-$
21	$\tilde{\mu}_R \tilde{\mu}_R$	46	$hZ$
22	$\tilde{\tau}_L \tilde{\tau}_L$	47	$HZ$
23	$\tilde{\tau}_R \tilde{\tau}_R$	48	$hA$
24	$\tilde{b}_1 \tilde{b}_1$	49	$HA$
25	$\tilde{b}_2 \tilde{b}_2$	50	$H^+ H^-$

Table 4: SUSY production process codes.

## B Gaugino Diagonalisation

### B.1 Mass matrices

The neutralino mass matrix in the base

$$\psi_l^0 = (-i\tilde{\gamma}, -i\tilde{Z}, \cos\beta\tilde{H}_1^0 - \sin\beta\tilde{H}_2^0, \sin\beta\tilde{H}_1^0 + \cos\beta\tilde{H}_2^0) \quad (38)$$

is given in section 2.1. The mass eigenstates can be computed by diagonalising Eq. (6). The diagonalisation is done numerically in SUSYGEN. In some calculations ( $R_p$  violating processes and gauge mediated processes) we use the base [42]:

$$\psi_k^0 = (-i\lambda_{\tilde{B}}, -i\lambda_{\tilde{W}_3}, \psi_{H1}^1, \psi_{H2}^2) \quad (39)$$

In this base the diagonalised neutralino coupling matrix  $N'_{ij}$  is defined in terms of the matrix  $N_{ij}$  as

$$\begin{aligned} N'_{1j} &= N_{1j} \cos(\theta_W) - N_{2j} \sin(\theta_W) \\ N'_{2j} &= N_{1j} \sin(\theta_W) + N_{2j} \cos(\theta_W) \\ N'_{3j} &= N_{3j} \cos(\beta) + N_{4j} \sin(\beta) \\ N'_{4j} &= -N_{3j} \sin(\beta) + N_{4j} \cos(\beta) \end{aligned} \quad (40)$$

The chargino mass matrix is also given in section 2.1. Here the chargino masses can be computed analytically:

$$M_{\chi_1^+, \chi_2^+}^2 = \frac{1}{2}[M_2^2 + \mu^2 + 2m_W^2 \mp \sqrt{(M_2^2 - \mu^2)^2 + 4m_W^4 \cos 2\beta + 4m_W^2(M_2^2 + \mu^2 + 2M_2\mu \sin 2\beta)}] \quad (41)$$

The chargino mixing matrices are given by

$$U_{12} = U_{21} = \frac{\theta_1}{\sqrt{2}} \sqrt{1 + \frac{M_2^2 - \mu^2 - 2m_W^2 \cos 2\beta}{W}} \quad (42)$$

$$U_{22} = -U_{11} = \frac{\theta_2}{\sqrt{2}} \sqrt{1 - \frac{M_2^2 - \mu^2 - 2m_W^2 \cos 2\beta}{W}} \quad (43)$$

$$V_{21} = -V_{12} = \frac{\theta_3}{\sqrt{2}} \sqrt{1 + \frac{M_2^2 - \mu^2 + 2m_W^2 \cos 2\beta}{W}} \quad (44)$$

$$V_{22} = V_{11} = \frac{\theta_4}{\sqrt{2}} \sqrt{1 - \frac{M_2^2 - \mu^2 + 2m_W^2 \cos 2\beta}{W}} \quad (45)$$

where  $W$  is given by

$$W = \sqrt{(M_2^2 + \mu^2 + 2m_W^2)^2 - 4(M_2\mu - m_W^2 \sin 2\beta)^2} \quad (46)$$

and the sign factors  $\theta_i$  are shown in table 5. The chargino and neutralino mass eigenvalues  $m_{\chi_k^+}, m_{\chi_n^0}$  can have positive or negative signs  $\eta_k = \pm 1, \eta_n = \pm 1$ , while the physical masses are defined positively, e.g.  $M_{\chi_k^+} = m_{\chi_k^+} \eta_k$ .

	$\tan \beta > 1$	$\tan \beta < 1$
$\theta_1$	1	$\varepsilon_B$
$\theta_2$	$\varepsilon_B$	1
$\theta_3$	$\varepsilon_A$	1
$\theta_4$	1	$\varepsilon_A$

Table 5: Sign factors  $\theta_i$ , where  $\varepsilon_A = \text{sign}(M_2 \sin \beta + \mu \cos \beta)$  and  $\varepsilon_B = \text{sign}(M_2 \cos \beta + \mu \sin \beta)$ .

## C Formulae

In the following we list the formulae which are used in SUSYGEN for the cross sections and the decay rates. The listing is given for completeness and easier understanding of the code, together with the original references.

### C.1 Cross sections

#### C.1.1 Neutralino pair production (processes 1-10)

Differential neutralino cross section (function GENPHO) [17];

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}|_Z + \frac{d\sigma}{dt}|\tilde{e} + \frac{d\sigma}{dt}|_{Z\tilde{e}} \quad (47)$$

$$\begin{aligned} \frac{d\sigma}{dt}|_Z &= \frac{g^4}{16\pi s^2 \cos^4 \theta_W} |D_z(s)|^2 |O_{ij}''^L|^2 (|L_e|^2 + |R_e|^2) \\ &\quad [(M_i^2 - t)(M_j^2 - t) + (M_i^2 - u)(M_j^2 - u) - 2\eta_i \eta_j M_i M_j s] \end{aligned} \quad (48)$$

$$\begin{aligned} \frac{d\sigma}{dt}|\tilde{e} &= \frac{g^4}{64\pi s^2} \{ |f_{li}^L|^2 |f_{lj}^L|^2 [|D_{\tilde{e}_L}(t)|^2 (M_i^2 - t)(M_j^2 - t) \\ &\quad + |D_{\tilde{e}_L}(u)|^2 (M_i^2 - u)(M_j^2 - u) - 2\text{Re}(D_{\tilde{e}_L}(t) D_{\tilde{e}_L}^*(u)) \eta_i \eta_j M_i M_j s] \\ &\quad + |f_{li}^R|^2 |f_{lj}^R|^2 [|D_{\tilde{e}_R}(t)|^2 (M_i^2 - t)(M_j^2 - t) \\ &\quad + |D_{\tilde{e}_R}(u)|^2 (M_i^2 - u)(M_j^2 - u) - 2\text{Re}(D_{\tilde{e}_R}(t) D_{\tilde{e}_R}^*(u)) \eta_i \eta_j M_i M_j s] \} \end{aligned} \quad (49)$$

$$\begin{aligned} \frac{d\sigma}{dt}|_{Z\tilde{e}} &= \frac{g^4}{16\pi s^2 \cos^2 \theta_W} \text{Re}(D_Z(s)) O_{ij}''^L \\ &\quad \{ L_e f_{li}^L f_{lj}^L [D_{\tilde{e}_L}(t)((M_i^2 - t)(M_j^2 - t) - \eta_i \eta_j M_i M_j s) \\ &\quad + D_{\tilde{e}_L}(u)((M_i^2 - u)(M_j^2 - u) - \eta_i \eta_j M_i M_j s)] \\ &\quad - R_e f_{li}^R f_{lj}^R [D_{\tilde{e}_R}(t)((M_i^2 - t)(M_j^2 - t) - \eta_i \eta_j M_i M_j s) \\ &\quad + D_{\tilde{e}_R}(u)((M_i^2 - u)(M_j^2 - u) - \eta_i \eta_j M_i M_j s)] \} \end{aligned} \quad (50)$$

where the Standard model couplings are;

$$e^2 = 4\pi\alpha \quad (51)$$

$$g = \frac{e}{\sin \theta_W} \quad (52)$$

$$L_f = T_3 - Q \sin^2 \theta_W \quad (53)$$

$$R_f = -Q \sin^2 \theta_W \quad (54)$$

$M_i$  and  $\eta_i$  are neutralino masses and diagonalisation phases, the couplings of the neutralino to sfermions are;

$$f_{li}^L = -\sqrt{2}[\frac{L_l}{\cos \theta_W} N_{i2} - \frac{R_l}{\sin \theta_W} N_{i1}] \quad (55)$$

$$f_{li}^R = \sqrt{2}R_l[\frac{1}{\cos \theta_W} N_{i2}^* - \frac{1}{\sin \theta_W} N_{i1}^*] \quad (56)$$

the neutralino couplings to Z are;

$$O_{ij}''^L = -\frac{1}{2}(N_{i3}N_{j3}^* - N_{i4}N_{j4}^*) \cos 2\beta - \frac{1}{2}(N_{i3}N_{j4}^* + N_{i4}N_{j3}^*) \sin 2\beta \quad (57)$$

$$O_{ij}''^R = -O_{ij}''^{L*} \quad (58)$$

and the propagators are;

$$D_Z(s) = (s - m_Z^2 + im_W \Gamma_Z)^{-1} \quad (59)$$

$$D_{\tilde{e}_{L,R}}(x) = (x - m_{\tilde{e}_{L,R}}^2)^{-1} \quad (60)$$

The integrated cross section (function PHOTI) is;

$$\sigma_{tot} = \frac{2 - \delta_{ij}}{2}(\sigma_Z + \sigma_{\tilde{e}} + \sigma_{Z\tilde{e}}) \quad (61)$$

$$\sigma_Z = \frac{g^4}{4\pi \cos^4 \theta_W} |D_Z(s)|^2 \frac{q}{\sqrt{s}} |O_{ij}''^L|^2 (|L_e|^2 + |R_e|^2) [E_i E_j + \frac{q^2}{3} - \eta_i \eta_j M_i M_j] \quad (62)$$

$$\sigma_{\tilde{e}} = \frac{g^4 q}{16\pi s \sqrt{s}} \quad (63)$$

$$\begin{aligned} & \{ |f_{ei}^L|^2 |f_{ej}^L|^2 [\frac{E_i E_j - s d_L + q^2}{s d_L^2 - q^2} + 2 + \frac{\sqrt{s}}{2q} (1 - 2d_L - \frac{\eta_i \eta_j M_i M_j}{s d_L}) \ln |\frac{d_L + \frac{q}{\sqrt{s}}}{d_L - \frac{q}{\sqrt{s}}}|] \\ & + |f_{ei}^R|^2 |f_{ej}^R|^2 [\frac{E_i E_j - s d_R + q^2}{s d_R^2 - q^2} + 2 + \frac{\sqrt{s}}{2q} (1 - 2d_R - \frac{\eta_i \eta_j M_i M_j}{s d_R}) \ln |\frac{d_R + \frac{q}{\sqrt{s}}}{d_R - \frac{q}{\sqrt{s}}}|] \} \end{aligned}$$

$$\begin{aligned} \sigma_{Z\tilde{e}} = & -\frac{g^4 q}{8\pi \cos^2 \theta_W \sqrt{s}} \text{Re}(D_Z(s)) O_{ij}''^L \\ & \{ L_e f_{ei}^L f_{ej}^L [\frac{E_i E_j - s d_L (1 - d_L) - \eta_i \eta_j M_i M_j}{q \sqrt{s}} \ln |\frac{d_L + \frac{q}{\sqrt{s}}}{d_L - \frac{q}{\sqrt{s}}}| + 2(1 - d_L)] \\ & - R_e f_{ei}^R f_{ej}^R [\frac{E_i E_j - s d_R (1 - d_R) - \eta_i \eta_j M_i M_j}{q \sqrt{s}} \ln |\frac{d_R + \frac{q}{\sqrt{s}}}{d_R - \frac{q}{\sqrt{s}}}| + 2(1 - d_R)] \} \end{aligned} \quad (64)$$

the phase space factors are;

$$d_{L,R} = \frac{1}{2s}(s + 2m_{\tilde{e}_{L,R}}^2 - M_i^2 - M_j^2) \quad (65)$$

$$E_i = \sqrt{q^2 + M_i^2} \quad (66)$$

where  $q$  is the CM momentum of the neutralinos.

### C.1.2 Chargino pair production (processes 11-13)

The differential chargino cross section (function GENCHAR) is [17];

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt} |_{\gamma} + \frac{d\sigma}{dt} |_Z \frac{d\sigma}{dt} |_{\tilde{\nu}} + \frac{d\sigma}{dt} |_{\gamma Z} \frac{d\sigma}{dt} |_{\gamma \tilde{\nu}} \frac{d\sigma}{dt} |_{Z \tilde{\nu}} \quad (67)$$

$$\frac{d\sigma}{dt} |_{\gamma} = \frac{e^4 \delta_{ij}}{8\pi s^4} [(M_i^2 - u)(M_j^2 - u) + (M_i^2 - t)(M_j^2 - t) + 2M_i M_j s] \quad (68)$$

$$\begin{aligned} \frac{d\sigma}{dt} |_Z = & \frac{g^4 |D_Z(s)|^2}{32\pi s^2 \cos^4 \theta_W} \{ (L_e^2 + R_e^2)(|O'_{ij}{}^L|^2 + |O'_{ij}{}^R|^2)[(M_i^2 - u)(M_j^2 - u) \\ & + (M_i^2 - t)(M_j^2 - t)] + 4(L_e^2 + R_e^2)O'_{ij}{}^L O'_{ij}{}^R \eta_i \eta_j M_i M_j s \\ & - (L_e^2 - R_e^2)(|O'_{ij}{}^L|^2 - |O'_{ij}{}^R|^2)[(M_i^2 - u)(M_j^2 - u) - (M_i^2 - t)(M_j^2 - t)] \} \end{aligned} \quad (69)$$

$$\frac{d\sigma}{dt} |_{\tilde{\nu}} = \frac{g^4 |D_{\tilde{\nu}}(t)|^2}{64\pi s^2} |V_{i1}|^2 |V_{j1}|^2 (M_i^2 - t)(M_j^2 - t) \quad (70)$$

$$\begin{aligned} \frac{d\sigma}{dt} |_{\gamma Z} = & \frac{e^2 g^2 \text{Re}(D_Z(s)) \delta_{ij}}{16\pi s^3 \cos^2 \theta_W} \{ (L_e + R_e)(O'_{ij}{}^L + O'_{ij}{}^R)[(M_i^2 - u)(M_j^2 - u) \\ & + (M_i^2 - t)(M_j^2 - t) + 2M_i M_j s] - (L_e - R_e)(O'_{ij}{}^L - O'_{ij}{}^R) \\ & [(M_i^2 - u)(M_j^2 - u) - (M_i^2 - t)(M_j^2 - t)] \} \end{aligned} \quad (71)$$

$$\frac{d\sigma}{dt} |_{\gamma \tilde{\nu}} = \frac{e^2 g^2 D_{\tilde{\nu}}(t) \delta_{ij}}{16\pi s^3} |V_{i1}|^2 [(M_i^2 - t)(M_j^2 - t) + M_i M_j s] \quad (72)$$

$$\frac{d\sigma}{dt} |_{Z \tilde{\nu}} = \frac{g^2 \text{Re}(D_{\tilde{\nu}}(t) D_Z^*(s))}{16\pi s^2 \cos^2 \theta_W} L_e V_{i1} V_{j1} [O'_{ij}{}^L (M_i^2 - t)(M_j^2 - t) + O'_{ij}{}^R \eta_i \eta_j M_i M_j s] \quad (73)$$

where the chargino couplings to the Z are;

$$O'_{ij}{}^L = -V_{i1} V_{j1}^* - \frac{1}{2} V_{i2} V_{j2}^* + \delta_{ij} \sin^2 \theta_W \quad (74)$$

$$O'_{ij}{}^R = -U_{i1}^* U_{j1} - \frac{1}{2} U_{i2}^* U_{j2} + \delta_{ij} \sin^2 \theta_W \quad (75)$$



and;

$$D_{\tilde{\nu}}(t) = (t - m_{\tilde{\nu}}^2)^{-1} \quad (76)$$

The total cross section is;

$$\sigma_{tot} = \sigma_{\gamma} + \sigma_Z + \sigma_{\tilde{\nu}} + \sigma_{\gamma Z} + \sigma_{\gamma\tilde{\nu}} + \sigma_{Z\tilde{\nu}} \quad (77)$$

$$\sigma_{\gamma} = \frac{e^4 q \sqrt{s} \delta_{ij}}{2\pi s^3} (E_i E_j + \frac{q^2}{3} + M_i M_j) \quad (78)$$

$$\begin{aligned} \sigma_Z = & \frac{g^4 q |D_Z(s)|^2}{8\pi \cos^4 \theta_W \sqrt{s}} [(|O'_{ij}{}^L|^2 + |O'_{ij}{}^R|^2)(L_e^2 + R_e^2) \\ & (E_i E_j + \frac{q^2}{3}) + 2(L_e^2 + R_e^2) O'_{ij}{}^L O'_{ij}{}^R \eta_i \eta_j M_i M_j] \end{aligned} \quad (79)$$

$$\begin{aligned} \sigma_{\tilde{\nu}} = & \frac{g^4 |V_{i1}|^2 |V_{j1}|^2 q}{32\pi \sqrt{s} m_{\tilde{\nu}}^4} [\frac{E_i E_j + q^2 - q\sqrt{s} \frac{a_L}{b_L}}{a_L^2 - b_L^2} + \frac{2q^2}{b_L^2} \\ & + \frac{1}{2b_L^2} (q\sqrt{s} - \frac{2q^2 a_L}{b_L}) \ln |\frac{a_L + b_L}{a_L - b_L}|] \end{aligned} \quad (80)$$

$$\begin{aligned} \sigma_{\gamma Z} = & \frac{e^2 g^2 q \sqrt{s}}{4\pi \cos^2 \theta_W s^2} \text{Re}(D_Z(s)) \delta_{ij} (L_e + R_e) (O'_{ij}{}^L + O'_{ij}{}^R) \\ & (E_i E_j + \frac{q^2}{3} + M_i M_j) \end{aligned} \quad (81)$$

$$\sigma_{\gamma\tilde{\nu}} = -\frac{e^2 g^2 |V_{i1}|^2 \delta_{ij}}{16\pi s^2} (h + M_i M_j \ln |\frac{a_L + b_L}{a_L - b_L}|) \quad (82)$$

$$\sigma_{Z\tilde{\nu}} = -\frac{g^4}{16\pi s \cos^2 \theta_W} V_{i1} V_{j1} \text{Re}(D_Z(s)) L_e (O'_{ij}{}^L h + O'_{ij}{}^R \eta_i \eta_j M_i M_j \ln |\frac{a_L + b_L}{a_L - b_L}|) \quad (83)$$

where the phase space factors are;

$$a_L = \frac{2m_{\tilde{\nu}}^2 + s - M_i^2 - M_j^2}{2m_{\tilde{\nu}}^2} \quad (84)$$

$$b_L = \frac{q\sqrt{s}}{m_{\tilde{\nu}}^2} \quad (85)$$

$$h = 2q\sqrt{s} - 2q^2 \frac{a_L}{b_L} + (E_i E_j + q^2 \frac{a_L^2}{b_L^2} - q\sqrt{s} \frac{a_L}{b_L}) \ln |\frac{a_L + b_L}{a_L - b_L}| \quad (86)$$

### C.1.3 Sneutrino production (processes 14-16)

The differential cross section (function GENSNUE) for  $\tilde{\nu}_e$  is [17];

$$\begin{aligned} \frac{d\sigma}{dt} = & \frac{g^4}{64\pi s^2}(ut - m_{\tilde{\nu}}^4) \left[ \frac{L_e^2 + R_e^2}{\cos^4 \theta_W} |D_Z(s)|^2 + \left( \sum_{k=1}^2 |V_{k1}|^2 D_k(t) \right)^2 \right. \\ & \left. + \frac{2L_e}{\cos^2 \theta_W} \text{Re}(D_Z(s)) \sum_{k=1}^2 |V_{k1}|^2 D_k(t) \right] \end{aligned} \quad (87)$$

where the  $t$  channel chargino propagators are;

$$D_k(t) = (t - M_k^2)^{-1} \quad (88)$$

For  $\tilde{\nu}$  other than  $\tilde{\nu}_e$  (function GENSNUE) only the first term is retained.

### C.1.4 Selectron production (processes 17-19)

The differential cross section (function GENSEL) is [17];

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt} |_{\gamma} + \frac{d\sigma}{dt} |_Z \frac{d\sigma}{dt} |_{\tilde{\chi}} + \frac{d\sigma}{dt} |_{\gamma Z} \frac{d\sigma}{dt} |_{\gamma \tilde{\chi}} + \frac{d\sigma}{dt} |_{Z \tilde{\chi}} \quad (89)$$

We obtain ;

(i)  $e^+ + e^- \longrightarrow \tilde{e}_1^+ + \tilde{e}_1^-$

$$\frac{d\sigma}{dt} |_{\gamma} = \frac{e^4}{8\pi s^4} (ut - m_{\tilde{e}_1}^4) \quad (90)$$

$$\frac{d\sigma}{dt} |_Z = \frac{g^4}{16\pi s^2 \cos^4 \theta_W} (ut - m_{\tilde{e}_1}^4) |D_Z(s)|^2 (L_e \cos^2 \phi + R_e \sin^2 \phi)^2 (L_e^2 + R_e^2) \quad (91)$$

$$\begin{aligned} \frac{d\sigma}{dt} |_{\tilde{\chi}} = & \frac{g^4}{64\pi s^2} \{ (ut - m_{\tilde{e}_1}^4) [\cos^4 \phi (\sum_{k=1}^4 D_k(t) |f_{ek}^L|^2)^2 + \sin^4 \phi (\sum_{k=1}^4 D_k(t) |f_{ek}^R|^2)^2] \\ & + 2s \sin^2 \phi \cos^2 \phi \sum_{k,l=1}^4 M_k M_l \eta_k \eta_l D_k(t) D_l(t) f_{ek}^R f_{ek}^L f_{el}^R f_{el}^L \} \end{aligned} \quad (92)$$

$$\frac{d\sigma}{dt} |_{\gamma Z} = \frac{e^2 g^2}{8\pi s^3 \cos^2 \theta_W} (ut - m_{\tilde{e}_1}^4) (L_e \cos^2 \phi + R_e \sin^2 \phi) (L_e + R_e) \text{Re}(D_Z(s)) \quad (93)$$

$$\frac{d\sigma}{dt} |_{\gamma \tilde{\chi}} = \frac{e^2 g^2}{16\pi s^3} (ut - m_{\tilde{e}_1}^4) \sum_{k=1}^4 D_k(t) (\cos^2 \phi |f_{ek}^L|^2 + \sin^2 \phi |f_{ek}^R|^2) \quad (94)$$

$$\begin{aligned} \frac{d\sigma}{dt} \big|_{Z\tilde{\chi}} &= \frac{g^4}{16\pi s^2 \cos^2 \theta_W} (ut - m_{\tilde{e}_1}^4) (L_e \cos^2 \phi + R_e \sin^2 \phi) \text{Re}(D_Z(s)) \\ &\quad \sum_{k=1}^4 D_k(t) (L_e |f_{ek}^L|^2 \cos^2 \phi + R_e |f_{ek}^R|^2 \sin^2 \phi) \end{aligned} \quad (95)$$

where the  $t$  channel neutralino propagators are;

$$D_k(t) = (t - M_k^2)^{-1} \quad (96)$$

and  $\phi$  is the L/R mixing angle;

$$\begin{aligned} \tilde{e}_1 &= \tilde{e}_L \cos \phi + \tilde{e}_R \sin \phi, \\ \tilde{e}_2 &= \tilde{e}_R \cos \phi - \tilde{e}_L \sin \phi \end{aligned} \quad (97)$$

(ii)  $e^+ + e^- \longrightarrow \tilde{e}_1^+ + \tilde{e}_2^-$  (function GENSELN)

$$\frac{d\sigma}{dt} \big|_{\gamma} = \frac{d\sigma}{dt} \big|_{\gamma Z} = \frac{d\sigma}{dt} \big|_{\gamma\tilde{\chi}} = 0 \quad (98)$$

$$\frac{d\sigma}{dt} \big|_Z = \frac{g^4}{16\pi s^2 \cos^4 \theta_W} (ut - m_{\tilde{e}_1}^2 m_{\tilde{e}_2}^2) \sin^2 \phi \cos^2 \phi |D_Z(s)|^2 (L_e - R_e)^2 (L_e^2 + R_e^2) \quad (99)$$

$$\begin{aligned} \frac{d\sigma}{dt} \big|_{\tilde{\chi}} &= \frac{g^4}{64\pi s^2} \{ (ut - m_{\tilde{e}_1}^2 m_{\tilde{e}_2}^2) \cos^2 \phi \sin^2 \phi [(\sum_{k=1}^4 D_k(t) |f_{ek}^L|^2)^2 + \\ &\quad (\sum_{k=1}^4 D_k(t) |f_{ek}^R|^2)^2] + s(\sin^4 \phi + \cos^4 \phi) \sum_{k,l=1}^4 M_k M_l \eta_k \eta_l D_k(t) D_l(t) f_{ek}^R f_{ek}^L f_{el}^R f_{el}^L \} \end{aligned} \quad (100)$$

$$\begin{aligned} \frac{d\sigma}{dt} \big|_{Z\tilde{\chi}} &= \frac{g^4}{16\pi s^2 \cos^2 \theta_W} (ut - m_{\tilde{e}_1}^2 m_{\tilde{e}_2}^2) \cos^2 \phi \sin^2 \phi (L_e - R_e) \text{Re}(D_Z(s)) \\ &\quad \sum_{k=1}^4 D_k(t) (L_e |f_{ek}^L|^2 - R_e |f_{ek}^R|^2) \end{aligned} \quad (101)$$

### C.1.5 Other charged sfermion cross sections (processes 20-35)

The differential cross section (function GENSMU) is;

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt} \big|_{\gamma} + \frac{d\sigma}{dt} \big|_Z + \frac{d\sigma}{dt} \big|_{\gamma Z} \quad (102)$$

$$\frac{d\sigma}{dt} |_{\gamma} = \frac{Q^2 e^2}{8\pi s^4} (ut - m_{\tilde{f}_1}^4) \quad (103)$$

$$\frac{d\sigma}{dt} |_Z = \frac{g^4}{16\pi s^2 \cos^4 \theta_W} (ut - m_{\tilde{f}_1}^4) |D_Z(s)|^2 (L_f \cos^2 \phi + R_f \sin^2 \phi)^2 (L_e^2 + R_e^2) \quad (104)$$

$$\frac{d\sigma}{dt} |_{\gamma Z} = \frac{Q^2 g^2}{8\pi s^3 \cos^2 \theta_W} (ut - m_{\tilde{f}_1}^4) (L_f \cos^2 \phi + R_f \sin^2 \phi) (L_e + R_e) \text{Re}(D_Z(s)) \quad (105)$$

The total cross section (function GENSMUS) is;

$$\sigma = \sigma_{\gamma} + \sigma_Z + \sigma_{\gamma Z} \quad (106)$$

$$\sigma_{\gamma} = \frac{Q^2 e^2}{8\pi s} \frac{\beta^3}{6} \quad (107)$$

$$\sigma_Z = \frac{g^4 s}{16\pi \cos^4 \theta_W} |D_Z(s)|^2 (L_f \cos^2 \phi + R_f \sin^2 \phi)^2 (L_e^2 + R_e^2) \frac{\beta^3}{6} \quad (108)$$

$$\sigma_{\gamma Z} = \frac{Q^2 g^2}{8\pi \cos^2 \theta_W} (L_f \cos^2 \phi + R_f \sin^2 \phi) (L_e + R_e) \text{Re}(D_Z(s)) \frac{\beta^3}{6} \quad (109)$$

Where  $\beta = \frac{2q}{\sqrt{s}}$

For  $\tilde{q}$  the above cross sections are multiplied by a QCD factor R;

$$R = 3(1 + \frac{4\alpha_s}{6\pi} (\frac{\pi^2}{\beta} - (1 + \beta)(\frac{\pi^2}{2} - 3))) \quad (110)$$

### C.1.6 Neutralino-Gravitino production (processes 36-39)

The cross section is given by [20]

$$\frac{d\sigma}{dt} = \frac{1}{16\pi s^2} \frac{F(s, t, u)}{\Lambda_S^4}, \quad (111)$$

$\Lambda_S^4 = 6(M_{PLANCK} m_{\tilde{G}})^2$  is the supersymmetry breaking scale, as a function of the Planck mass and the mass of the gravitino.

$$F(s, t, u) = F_{\gamma\gamma} + F_{tt} + F_{uu} + F_{ZZ} + F_{\gamma t} + F_{\gamma u} + F_{Zt} + F_{Zu} + F_{\gamma Z}, \quad (112)$$

where

$$F_{\gamma\gamma} = (N_{i1}e)^2 \frac{2s(s - m_\chi^2)(t^2 + u^2)}{s^2} \quad (113)$$

$$F_{tt} = (X_R)^2 \frac{t^2(m_\chi^2 - t)(-t)}{(t - m_{\tilde{e}_R}^2)^2} + (X_L)^2 \frac{t^2(m_\chi^2 - t)(-t)}{(t - m_{\tilde{e}_L}^2)^2} \quad (114)$$

$$F_{uu} = (X_R)^2 \frac{u^2(m_\chi^2 - u)(-u)}{(u - m_{\tilde{e}_R}^2)^2} + (X_L)^2 \frac{u^2(m_\chi^2 - u)(-u)}{(u - m_{\tilde{e}_L}^2)^2} \quad (115)$$

$$F_{ZZ} = \left( N_{i2} \frac{g}{\cos \theta_W} \right)^2 \frac{(R_e^2 + L_e^2)}{2} \frac{2s(s - m_\chi^2)(t^2 + u^2)}{(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2} \quad (116)$$

$$F_{\gamma t} = (N_{i1} e X_R) \frac{(-t)(2st^2)}{s(t - m_{\tilde{e}_R}^2)} - (N_{i1} e X_L) \frac{(-t)(2st^2)}{s(t - m_{\tilde{e}_L}^2)} \quad (117)$$

$$F_{\gamma u} = (N_{i1} e X_R) \frac{(-u)(2su^2)}{s(u - m_{\tilde{e}_R}^2)} - (N_{i1} e X_L) \frac{(-u)(2su^2)}{s(u - m_{\tilde{e}_L}^2)} \quad (118)$$

$$F_{Zt} = - \left( N_{i2} R_e X_R \frac{g}{\cos \theta_W} \right) \frac{(-t)(2st^2)(s - M_Z^2)}{[(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2](t - m_{\tilde{e}_R}^2)} \\ + \left( N_{i2} L_e X_L \frac{g}{\cos \theta_W} \right) \frac{(-t)(2st^2)(s - M_Z^2)}{[(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2](t - m_{\tilde{e}_L}^2)} \quad (119)$$

$$F_{Zu} = - \left( N_{i2} R_e X_R \frac{g}{\cos \theta_W} \right) \frac{(-u)(2su^2)(s - M_Z^2)}{[(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2](u - m_{\tilde{e}_R}^2)} \\ + \left( N_{i2} L_e X_L \frac{g}{\cos \theta_W} \right) \frac{(-u)(2su^2)(s - M_Z^2)}{[(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2](u - m_{\tilde{e}_L}^2)} \quad (120)$$

$$F_{\gamma Z} = -2 \left( N_{i1} N_{i2} e \frac{g}{\cos \theta_W} \right) \frac{(R_e + L_e)}{2} \frac{2s(s - m_\chi^2)(t^2 + u^2)(s - M_Z^2)}{s[(s - M_Z^2)^2 + (\Gamma_Z M_Z)^2]} \quad (121)$$

and:

$$X_R = N_{i1} e - N_{i2} \frac{g R_e}{\cos \theta_W} \quad (122)$$

$$X_L = -N_{i1} e - N_{i2} \frac{g}{\cos \theta_W} L_e \quad (123)$$

### C.1.7 S-channel Sneutrino resonance cross sections (processes 40-45)

The  $R_p$  violating single sparticle production processes 40-45 are characterised by a sneutrino s-channel resonance for a non-zero coupling  $\lambda_{121}$  or  $\lambda_{131}$ . The s-channel sneutrino process  $e^+e^- \rightarrow \tilde{\nu}_j$  has three principal decay modes:

$$e^+e^- \rightarrow \tilde{\nu}_j \rightarrow e^+e^- \quad (124)$$

$$e^+e^- \rightarrow \tilde{\nu}_j \rightarrow \chi^0 \nu_j \quad (125)$$

$$e^+e^- \rightarrow \tilde{\nu}_j \rightarrow \chi^+ l_j^- \quad (126)$$

but only the single chargino/neutralino processes (125),(126) are implemented in SUSYGEN.

### C.1.8 Single Chargino Production

Ignoring contributions to the vertices of the MSSM from mass terms, we have two channels present ( $s$  and  $t$ ) for chargino production [23]:

$$\sigma_{e^+e^- \rightarrow l_j^\mp \tilde{\chi}_m^\pm} = \frac{1}{64\pi s^2} \left( \frac{V_{m1}\lambda_{1j1}e}{\sin\theta_W} \right)^2 \left\{ \frac{C_s}{(s - m_{\tilde{\nu}_j}^2)^2 + \Gamma_{\tilde{\nu}}^2 m_{\tilde{\nu}_j}^2} + \frac{C_t}{(t - m_{\tilde{\nu}_e}^2)^2} - \frac{C_{st}(s - m_{\tilde{\nu}_j}^2)}{[(s - m_{\tilde{\nu}_j}^2)^2 + \Gamma_{\tilde{\nu}}^2 m_{\tilde{\nu}_j}^2](t - m_{\tilde{\nu}_e}^2)} \right\} \quad (127)$$

where

$$\begin{aligned} C_s &= s(s - m_{\tilde{\chi}^\pm}^2), & C_t &= t(t - m_{\tilde{\chi}^\pm}^2) \\ C_{st} &= s(s - m_{\tilde{\chi}^\pm}^2) + t(t - m_{\tilde{\chi}^\pm}^2) - u(u - m_{\tilde{\chi}^\pm}^2) \end{aligned} \quad (128)$$

Here  $s$ ,  $t$  and  $u$  are the Mandelstam variables

$$t = (e^- - \tilde{\chi}^\pm)^2, \quad u = (e^+ - \tilde{\chi}^\pm)^2, \quad (129)$$

and the width of the sneutrino is given by

$$\Gamma_{\tilde{\nu}_j} = \Gamma_1 + \Gamma_2 \quad (130)$$

where the  $R_p$  violating sneutrino decay rate  $\Gamma_1 \equiv \tilde{\nu}_j \rightarrow e^i e^k = \frac{\lambda_{1j1}^2}{16\pi} m_{\tilde{\nu}_j}$ ; and the  $R_p$  conserving decay rate  $\Gamma_2 \equiv \tilde{\nu}_j \rightarrow \tilde{\chi}_m^\pm l_j^\mp$ .

### C.1.9 Single Neutralino Production

Ignoring mass terms the cross-section for this process is given by [23]:

$$\begin{aligned} \sigma_{e^+e^- \rightarrow \nu \tilde{\chi}_m^0} &= \frac{1}{32\pi s^2} \lambda_{1j1}^2 \left\{ V_1^2 \frac{C_s}{(s - m_{\tilde{\nu}_j}^2)^2 + \Gamma_{\tilde{\nu}}^2 m_{\tilde{\nu}_j}^2} + V_2^2 \frac{C_t}{(t - m_{\tilde{e}_L}^2)^2} + V_3^2 \frac{C_u}{(u - m_{\tilde{e}_R}^2)^2} \right. \\ &\quad - V_1 V_2^* \frac{C_{st}(s - m_{\tilde{\nu}_j}^2)}{[(s - m_{\tilde{\nu}_j}^2)^2 + \Gamma_{\tilde{\nu}}^2 m_{\tilde{\nu}_j}^2](t - m_{\tilde{e}_L}^2)} - V_1 V_3^* \frac{C_{su}(s - m_{\tilde{\nu}_j}^2)}{[(s - m_{\tilde{\nu}_j}^2)^2 + \Gamma_{\tilde{\nu}}^2 m_{\tilde{\nu}_j}^2](u - m_{\tilde{e}_R}^2)} \\ &\quad \left. - V_2 V_3^* \frac{C_{tu}}{(t - m_{\tilde{e}_L}^2)(u - m_{\tilde{e}_R}^2)} \right\} \end{aligned} \quad (131)$$

where

$$\begin{aligned} V_1 &= -\frac{1}{2} \frac{g}{\cos\theta_W} N_{m2}'^* \\ V_2 &= -e N_{m1}'^* - \frac{g}{\cos\theta_W} \left( \frac{1}{2} - \sin^2\theta_W \right) N_{m2}'^* \\ V_3 &= -e N_{jm}'^* + \frac{g \sin\theta_W^2}{\cos\theta_W} N_{m2}'^* \end{aligned} \quad (132)$$

Here the functions  $C_s$ ,  $C_t$ , and  $C_{st}$  are given as before, just replacing the chargino mass  $m_{\tilde{\chi}^\pm}$  by the neutralino mass  $m_{\tilde{\chi}^0}$ . The new functions  $C_u$ ,  $C_{su}$  and  $C_{ut}$  are given by

$$\begin{aligned} C_u &= u(u - m_{\tilde{\chi}^0}^2) \\ C_{su} &= s(s - m_{\tilde{\chi}^0}^2) - t(t - m_{\tilde{\chi}^0}^2) + u(u - m_{\tilde{\chi}^0}^2) \\ C_{tu} &= -s(s - m_{\tilde{\chi}^0}^2) + t(t - m_{\tilde{\chi}^0}^2) + u(u - m_{\tilde{\chi}^0}^2) \end{aligned} \quad (133)$$

And the  $R_p$  conserving decay rate  $\Gamma_2 \equiv \tilde{\nu}_j \rightarrow \tilde{\chi}_m^0 \nu_j$ .

## C.2 Decay Rates

### C.3 Gaugino-Higgsino three body decay rates

The general 3-body decay from a chargino/neutralino to a chargino/neutralino and 2 fermions can be parametrised as [17];

$$\Gamma(\tilde{\chi}_i \rightarrow \tilde{\chi}_k + f \bar{f}') = \frac{\alpha^2}{32\pi \sin^4 \theta_W M_i^3} \int d\bar{s} d\bar{t} (W_s + W_t + W_u + W_{tu} + W_{st} + W_{su}) \quad (134)$$

$$W_s = \frac{1}{(\bar{s} - M_s^2)^2 + G_s^2} \{A_s(M_i^2 - \bar{t})(\bar{t} - M_k^2) + B_s(M_i^2 - \bar{u})(\bar{u} - M_k^2) + 2C_s \eta_i \eta_k M_i M_k \bar{s}\} \quad (135)$$

$$W_t = A_t^L \frac{(M_i^2 - \bar{t})(\bar{t} - M_k^2)}{(\bar{t} - M_L^2)^2 + G_L^2} + A_t^R \frac{(M_i^2 - \bar{t})(\bar{t} - M_k^2)}{(\bar{t} - M_R^2)^2 + G_R^2} \quad (136)$$

$$W_u = A_u^L \frac{(M_i^2 - \bar{u})(\bar{u} - M_k^2)}{(\bar{u} - M_L^2)^2 + G_L^2} + A_u^R \frac{(M_i^2 - \bar{u})(\bar{u} - M_k^2)}{(\bar{u} - M_R^2)^2 + G_R^2} \quad (137)$$

$$\begin{aligned} W_{tu} &= 2A_{tu}^L \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{t} - M_L^2)(\bar{u} - M_L^2) + G_L^2}{[(\bar{t} - M_L^2)^2 + G_L^2][(\bar{u} - M_L^2)^2 + G_L^2]} \\ &\quad + 2A_{tu}^R \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{t} - M_R^2)(\bar{u} - M_R^2) + G_R^2}{[(\bar{t} - M_R^2)^2 + G_R^2][(\bar{u} - M_R^2)^2 + G_R^2]} \end{aligned} \quad (138)$$

$$\begin{aligned} W_{st} &= 2A_{st}^L (M_i^2 - \bar{t})(\bar{t} - M_k^2) \frac{(\bar{t} - M_L^2)(\bar{s} - M_s^2) + G_L G_s}{[(\bar{t} - M_L^2)^2 + G_L^2][(\bar{s} - M_s^2)^2 + G_s^2]} \\ &\quad + 2B_{st}^L \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{t} - M_L^2)(\bar{s} - M_s^2) + G_L G_s}{[(\bar{t} - M_L^2)^2 + G_L^2][(\bar{s} - M_s^2)^2 + G_s^2]} \\ &\quad + 2A_{st}^R (M_i^2 - \bar{t})(\bar{t} - M_k^2) \frac{(\bar{t} - M_R^2)(\bar{s} - M_s^2) + G_R G_s}{[(\bar{t} - M_R^2)^2 + G_R^2][(\bar{s} - M_s^2)^2 + G_s^2]} \\ &\quad + 2B_{st}^R \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{t} - M_R^2)(\bar{s} - M_s^2) + G_R G_s}{[(\bar{t} - M_R^2)^2 + G_R^2][(\bar{s} - M_s^2)^2 + G_s^2]} \end{aligned} \quad (139)$$

$$\begin{aligned} W_{su} &= 2A_{su}^L (M_i^2 - \bar{u})(\bar{u} - M_k^2) \frac{(\bar{u} - M_L^2)(\bar{s} - M_s^2) + G_L G_s}{[(\bar{u} - M_L^2)^2 + G_L^2][(\bar{s} - M_s^2)^2 + G_s^2]} \\ &\quad + 2B_{su}^L \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{u} - M_L^2)(\bar{s} - M_s^2) + G_L G_s}{[(\bar{u} - M_L^2)^2 + G_L^2][(\bar{s} - M_s^2)^2 + G_s^2]} \end{aligned} \quad (140)$$

$$\begin{aligned}
& +2A_{su}^R(M_i^2 - \bar{u})(\bar{u} - M_k^2) \frac{(\bar{u} - M_R^2)(\bar{s} - M_s^2) + G_R G_s}{[(\bar{u} - M_R^2)^2 + G_R^2][(\bar{s} - M_s^2)^2 + G_s^2]} \\
& +2B_{su}^R \eta_i \eta_k M_i M_k \bar{s} \frac{(\bar{u} - M_R^2)(\bar{s} - M_s^2) + G_R G_s}{[(\bar{u} - M_R^2)^2 + G_R^2][(\bar{s} - M_s^2)^2 + G_s^2]}
\end{aligned}$$

where the factors  $G_i$  are;  $G_s = \Gamma_s M_s$ ,  $G_L = \Gamma_L M_L$ ,  $G_R = \Gamma_R M_R$ ,  $G_\nu = \Gamma_\nu M_{\tilde{\nu}}$ ,  $G_k = \Gamma_k M_k$ ,  $G_l = \Gamma_l M_l$  and the chargino-neutralino couplings are;

$$O_{ij}^L = -(N_{i4} \cos \beta - N_{i3} \sin \beta) \frac{V_{j2}^*}{\sqrt{2}} + (N_{i1} \sin \theta_W + N_{i3} \cos \theta_W) V_{j1}^* \quad (141)$$

$$O_{ij}^R = (N_{i4}^* \sin \beta + N_{i3}^* \cos \beta) \frac{U_{j2}}{\sqrt{2}} + (N_{i1}^* \sin \theta_W + N_{i3}^* \cos \theta_W) U_{j1} \quad (142)$$

and the tables 6, 7, 8 and 9 contain the definitions of the A, B and C parameters.

$\tilde{\chi}_i^+ \longrightarrow$	$\tilde{\chi}_k^0 l^+ \nu$	$\tilde{\chi}_k^+ l^+ l^-$	$\tilde{\chi}_k^+ \nu \tilde{\nu}$
$A_s$	$2(O_{ki}^L)^2$	$4 \frac{(L_l O_{ki}^{'L})^2 + (R_l O_{ki}^{'R})^2}{\cos^4 \theta_W}$	$\frac{(O_{ki}^{'L})^2}{\cos^4 \theta_W}$
$B_s$	$2(O_{ki}^R)^2$	$4 \frac{(L_l O_{ki}^{'R})^2 + (R_l O_{ki}^{'L})^2}{\cos^4 \theta_W}$	$\frac{(O_{ki}^{'R})^2}{\cos^4 \theta_W}$
$C_s$	$-2O_{ki}^L O_{ki}^R$	$-4 \frac{(L_l^2 + R_l^2) O_{ki}^{'L} O_{ki}^{'R}}{\cos^4 \theta_W}$	$-\frac{O_{ki}^{'L} O_{ki}^{'R}}{\cos^4 \theta_W}$
$A_t^L$	$(f_{\nu k}^L V_{i1})^2$	$(V_{k1} V_{i1})^2$	0
$A_u^L$	$(f_{lk}^L U_{i1})^2$	0	$(U_{k1} U_{i1})^2$
$A_{tu}^L$	$f_{\nu k}^L f_{lk}^L V_{i1} U_{i1}$	0	0
$A_{st}^L$	$-\sqrt{2} f_{\nu k}^L V_{i1} O_{ki}^L$	$2 \frac{V_{k1} V_{i1} O_{ki}^{'L} L_l}{\cos^2 \theta_W}$	0
$B_{st}^L$	$\sqrt{2} f_{\nu k}^L V_{i1} O_{ki}^R$	$-2 \frac{V_{k1} V_{i1} O_{ki}^{'R} L_l}{\cos^2 \theta_W}$	0
$A_{su}^L$	$\sqrt{2} f_{lk}^L U_{i1} O_{ki}^R$	0	$-\frac{U_{k1} U_{i1} O_{ki}^{'R}}{\cos^2 \theta_W}$
$B_{su}^L$	$-\sqrt{2} f_{lk}^L U_{i1} O_{ki}^L$	0	$\frac{U_{k1} U_{i1} O_{ki}^{'L}}{\cos^2 \theta_W}$

Table 6: Coefficients for leptonic chargino decays

#### C.4 Gaugino two body and radiative decay rates

The above three-body branching ratio formulas include the width of the exchanged particles in the propagator terms, and therefore smoothly converge to a two-body formula when above threshold. For example if the sneutrino is lighter than the chargino and the neutralino is the LSP, the three-body decay rate  $\Gamma(\chi^+ \rightarrow l^+ \nu \chi^0)$  is the same as the two-body decay rate  $\Gamma(\chi^+ \rightarrow l^+ \tilde{\nu})$ . Furthermore the kinematics of the three-body decay is equivalent to the two-body decay kinematics (once the sneutrino decay  $\tilde{\nu} \rightarrow \nu \chi^0$  has been included). The procedure has been numerically checked with the explicit 2-body calculations, and the branching ratios, partial decay widths and kinematics agree well.

Sometimes it is useful to calculate the gaugino two-body decays explicitly (for example for  $R_p$  violating models). The gaugino decay rate to a lighter sfermion is given by:

$$\Gamma(\chi \rightarrow \tilde{f} f') = c_f \frac{1}{16\pi m_\chi^3} \sqrt{(m_\chi^2 - (m_{\tilde{f}} + m_{f'})^2)(m_\chi^2 - (m_{\tilde{f}} - m_{f'})^2)}$$



$\tilde{\chi}_i^+ \longrightarrow$	$\tilde{\chi}_k^0 u \tilde{d}$	$\tilde{\chi}_k^+ u \tilde{u}$	$\tilde{\chi}_k^+ d \tilde{d}$
$A_s$	$6(O_{ki}^L)^2$	$12 \frac{(L_u O_{ki}^{'L})^2 + (R_u O_{ki}^{'R})^2}{\cos^4 \theta_W}$	$12 \frac{(L_d O_{ki}^{'L})^2 + (R_d O_{ki}^{'R})^2}{\cos^4 \theta_W}$
$B_s$	$6(O_{ki}^R)^2$	$12 \frac{(L_u O_{ki}^{'R})^2 + (R_u O_{ki}^{'L})^2}{\cos^4 \theta_W}$	$12 \frac{(L_d O_{ki}^{'R})^2 + (R_d O_{ki}^{'L})^2}{\cos^4 \theta_W}$
$C_s$	$-12 O_{ki}^L O_{ki}^R$	$-12 \frac{(L_u^2 + R_u^2) O_{ki}^{'L} O_{ki}^{'R}}{\cos^4 \theta_W}$	$-12 \frac{(L_d^2 + R_d^2) O_{ki}^{'L} O_{ki}^{'R}}{\cos^4 \theta_W}$
$A_t^L$	$3(f_{uk}^L V_{i1})^2$	0	$3(V_{k1} V_{i1})^2$
$A_u^L$	$3(f_{dk}^L U_{i1})^2$	$3(U_{k1} U_{i1})^2$	0
$A_{tu}^L$	$3f_{uk}^L f_{dk}^L V_{i1} U_{i1}$	0	0
$A_{st}^L$	$-3\sqrt{2} f_{uk}^L V_{i1} O_{ki}^L$	0	$6 \frac{V_{k1} V_{i1} O_{ki}^{'L} L_d}{\cos^2 \theta_W}$
$B_{st}^L$	$3\sqrt{2} f_{uk}^L V_{i1} O_{ki}^R$	0	$-6 \frac{V_{k1} V_{i1} O_{ki}^{'R} L_d}{\cos^2 \theta_W}$
$A_{su}^L$	$3\sqrt{2} f_{dk}^L U_{i1} O_{ki}^R$	$-6 \frac{U_{k1} U_{i1} O_{ki}^{'R} L_u}{\cos^2 \theta_W}$	0
$B_{su}^L$	$-3\sqrt{2} f_{dk}^L U_{i1} O_{ki}^L$	$6 \frac{U_{k1} U_{i1} O_{ki}^{'L} L_u}{\cos^2 \theta_W}$	0

Table 7: Coefficients for hadronic chargino decays

$\tilde{\chi}_i^0 \longrightarrow$	$\tilde{\chi}_k^0 l^+ l^-$	$\tilde{\chi}_k^0 \nu \tilde{\nu}$	$\tilde{\chi}_k^0 q \tilde{q}$
$A_s = B_s = C_s$	$4 \frac{(L_l^2 + R_l^2) O_{ki}^{'L}}{\cos^4 \theta_W}$	$\frac{(O_{ki}^{'L})^2}{\cos^4 \theta_W}$	$12 \frac{(L_q^2 + R_q^2) O_{ki}^{'L}}{\cos^4 \theta_W}$
$A_t^L = A_u^L = A_{tu}^L$	$(f_{lk}^L f_{li}^L)^2$	$(f_{\nu k}^L f_{\nu i}^L)^2$	$3(f_{qk}^L f_{qi}^L)^2$
$A_t^R = A_u^R = A_{tu}^R$	$(f_{lk}^R f_{li}^R)^2$	0	$3(f_{qk}^R f_{qi}^R)^2$
$A_{st}^L = B_{st}^L = A_{su}^L = B_{su}^L$	$2 \frac{f_{lk}^L f_{li}^L O_{ki}^{'L} L_l}{\cos^2 \theta_W}$	$\frac{f_{\nu k}^L f_{\nu i}^L O_{ki}^{'L}}{\cos^2 \theta_W}$	$6 \frac{f_{qk}^L f_{qi}^L O_{ki}^{'L} L_q}{\cos^2 \theta_W}$
$A_{st}^R = B_{st}^R = A_{su}^R = B_{su}^R$	$2 \frac{f_{lk}^R f_{li}^R O_{ki}^{'R} R_l}{\cos^2 \theta_W}$	0	$6 \frac{f_{qk}^R f_{qi}^R O_{ki}^{'R} R_q}{\cos^2 \theta_W}$

Table 8: Coefficients for  $\tilde{\chi}_i^0 \longrightarrow \tilde{\chi}_k^0 f \tilde{f}'$

$$\times \mathcal{M}_{\tilde{\chi} \tilde{f} f'} \quad (143)$$

where  $c_f = 3$  is the colour factor for gaugino decays to squarks ( $c_f = 1$  for sleptons and sneutrinos). And

$$M_{\tilde{\chi} \tilde{f} f'} = 2\sqrt{(m_{\tilde{\chi}}^2 - (m_{\tilde{f}} + m_{f'})^2)(m_{\tilde{\chi}}^2 - (m_{\tilde{f}} - m_{f'})^2) + 4m_{\tilde{\chi}}^2 m_{f'}^2 \{a^2 + b^2\}} \quad (144)$$

where the gaugino coupling to the sfermion is parametrised as  $i\{a(1 + \gamma_5) + b(1 - \gamma_5)\}$ ; and the constants a,b are for example given in [42], Fig. 22-24. Note that for gaugino decays to third generation sfermions mixing must be taken into account by modifying the constants a,b and the sfermion mass appropriately.

The gaugino decay rate to a gauge boson (W or Z) is again given by Eq. (143), and the coupling constants a,b are given in [44] (Fig. 75).

The two-body decay rates for the neutralino decays to a lighter neutralino plus a Higgs boson are

$\tilde{\chi}_i^o \longrightarrow$	$\tilde{\chi}_k^+ l^- \tilde{\nu}$	$\tilde{\chi}_k^+ u \tilde{d}$
$A_s$	$2(O_{ki}^L)^2$	$6(O_{ki}^L)^2$
$B_s$	$2(O_{ki}^R)^2$	$6(O_{ki}^R)^2$
$C_s$	$-2O_{ki}^L O_{ki}^R$	$-6O_{ki}^L O_{ki}^R$
$A_t^L$	$(f_{\nu i}^L V_{k1})^2$	$3(f_{ui}^L V_{k1})^2$
$A_u^L$	$(f_{li}^L U_{k1})^2$	$3(f_{di}^L U_{k1})^2$
$A_{tu}^L$	$f_{\nu i}^L f_{li}^L V_{k1} U_{k1}$	$3f_{ui}^L f_{di}^L V_{k1} U_{k1}$
$A_{st}^L$	$-\sqrt{2}f_{\nu i}^L V_{k1} O_{ik}^L$	$-3\sqrt{2}f_{ui}^L V_{k1} O_{ik}^L$
$B_{st}^L$	$\sqrt{2}f_{\nu i}^L V_{k1} O_{ik}^R$	$3\sqrt{2}f_{ui}^L V_{k1} O_{ik}^R$
$A_{su}^L$	$\sqrt{2}f_{li}^L U_{k1} O_{ik}^R$	$3\sqrt{2}f_{di}^L U_{k1} O_{ik}^R$
$B_{su}^L$	$-\sqrt{2}f_{li}^L U_{k1} O_{ik}^L$	$-3\sqrt{2}f_{di}^L U_{k1} O_{ik}^L$

Table 9: Coefficients for  $\tilde{\chi}_i^o \longrightarrow \tilde{\chi}_k^+ f \tilde{f}'$

given by [43]:

$$\Gamma(\chi_i \rightarrow \chi_j H_k^0) = \frac{g^2 \lambda(M_i, M_j, M_k)^{\frac{1}{2}}}{32\pi M_i^3} [(F_{ijk}^2 + F_{jik}^2)(M_i^2 + M_j^2 - M_H^2) + 4F_{ijk} F_{jik} \epsilon_i \epsilon_j \eta'_k M_i M_j]$$

where  $k=1,2,3$  correspond to the three neutral Higgs  $h, H, A$ ;  $\eta'_k = 1$  for  $k = 1, 2$  and  $\eta'_k = -1$  for  $k = 3$ ; the factors  $\epsilon_i$  stand for the sign of the neutralino mass; the kinematic function  $\lambda$  is defined by

$$\lambda(a, b, c) = a^2 + b^2 - c^2 - 4a^2 b^2 \quad (145)$$

and

$$F_{ijk} = \frac{c_k}{2\sin\beta} [N'_{3i} N'_{2j} + N'_{3j} N'_{2i} - \tan\theta_W (N'_{3i} N'_{1j} + N'_{3j} N'_{1i})] + \frac{d_k}{2m_W \sin\beta} [M N'_{2i} N'_{2j} + M' N'_{1i} N'_{1j} - \mu (N'_{3i} N'_{4j} + N'_{4i} N'_{3j})] \quad (146)$$

where  $M, M', \mu$  are the usual neutralino mixing parameters, and the constants  $c_k, d_k$  are given by

$$\begin{aligned} c_1 &= \sin(\beta - \alpha) \quad , \quad d_1 = -\sin(\alpha) \\ c_2 &= \cos(\beta - \alpha) \quad , \quad d_2 = \cos(\alpha) \\ c_3 &= \cos(2\beta) \quad , \quad d_3 = \cos(\beta). \end{aligned} \quad (147)$$

The two-body decay rates for the neutralino decays to a lighter chargino plus a charged Higgs boson are given by [43]:

$$\Gamma(\chi_i \rightarrow \chi_j^\pm H^\mp) = \frac{g^2 \lambda(M_i, M_j, M_{H^\pm})^{\frac{1}{2}}}{32\pi M_i^3} [(F_L^2 + F_R^2)(M_i^2 + M_j^2 - M_H^2) + 4F_L F_R \epsilon_i \epsilon_j M_i M_j] \quad (148)$$

where

$$\begin{aligned} F_L &= \cos\beta [N'_{4i} V_{j1} + \frac{1}{\sqrt{2}} (N'_{2i} + N'_{1i} \tan\theta_W) V_{j2}] \\ F_R &= \sin\beta [N'_{3i} U_{j1} - \frac{1}{\sqrt{2}} (N'_{2i} + N'_{1i} \tan\theta_W) U_{j2}]. \end{aligned} \quad (149)$$

Finally the radiative two-body decays occurring through loop-diagrams have the general form:

$$\Gamma(\tilde{\chi}_j^0 \rightarrow \tilde{\chi}_i^0 \gamma) = \frac{g_{\tilde{\chi}_j^0 \tilde{\chi}_i^0 \gamma}^2 (M_j^2 - M_i^2)^3}{8\pi M_j^5} \quad (150)$$

The expressions for  $g_{\tilde{\chi}_j^0 \tilde{\chi}_i^0 \gamma}^2$  can be found in [18].

### C.5 Sfermion decay rates

The most general sfermion decay widths are:

$$\Gamma(\tilde{f}_i \rightarrow f \tilde{\chi}_k^0) = \frac{g^2 \lambda^{\frac{1}{2}}(m_{\tilde{f}_i}^2, m_f^2, m_{\tilde{\chi}_k^0}^2)}{16\pi m_{\tilde{f}_i}^3} \left[ (a_{ik}^2 + b_{ik}^2)(m_{\tilde{f}_i}^2 - m_f^2 - m_{\tilde{\chi}_k^0}^2) - 4a_{ik}b_{ik}m_fm_{\tilde{\chi}_k^0} \right] \quad (151)$$

and

$$\Gamma(\tilde{f}_i \rightarrow f' \tilde{\chi}_j^\pm) = \frac{g^2 \lambda^{\frac{1}{2}}(m_{\tilde{f}_i}^2, m_{f'}^2, m_{\tilde{\chi}_j^\pm}^2)}{16\pi m_{\tilde{f}_i}^3} \left[ (l_{ij}^2 + k_{ij}^2)(m_{\tilde{f}_i}^2 - m_{f'}^2 - m_{\tilde{\chi}_j^\pm}^2) - 4l_{ij}k_{ij}m_{f'}m_{\tilde{\chi}_j^\pm} \right] \quad (152)$$

where  $\lambda(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2xz - 2yz$ .

and where:

$$\begin{pmatrix} a_{1k}^f \\ a_{2k}^f \end{pmatrix} = \begin{pmatrix} \cos \theta_{\tilde{f}} & \sin \theta_{\tilde{f}} \\ -\sin \theta_{\tilde{f}} & \cos \theta_{\tilde{f}} \end{pmatrix} \begin{pmatrix} h_{Lk}^f \\ f_{Rk}^f \end{pmatrix}, \quad \begin{pmatrix} b_{1k}^f \\ b_{2k}^f \end{pmatrix} = \begin{pmatrix} \cos \theta_{\tilde{f}} & \sin \theta_{\tilde{f}} \\ -\sin \theta_{\tilde{f}} & \cos \theta_{\tilde{f}} \end{pmatrix} \begin{pmatrix} f_{Lk}^f \\ h_{Rk}^f \end{pmatrix}, \quad (153)$$

$$\begin{aligned} h_{Lk}^t &= Y_t (N_{k3} \sin \beta - N_{k4} \cos \beta), & f_{Lk}^t &= -\frac{2\sqrt{2}}{3} \sin \theta_W N_{k1} - \sqrt{2} \left( \frac{1}{2} - \frac{2}{3} \sin^2 \theta_W \right) \frac{N_{k2}}{\cos \theta_W}, \\ h_{Rk}^t &= Y_t (N_{k3} \sin \beta - N_{k4} \cos \beta), & f_{Rk}^t &= -\frac{2\sqrt{2}}{3} \sin \theta_W (\tan \theta_W N_{k2} - N_{k1}), \end{aligned} \quad (154)$$

$$\begin{aligned} h_{Lk}^b &= -Y_b (N_{k3} \cos \beta + N_{k4} \sin \beta), & f_{Lk}^b &= \frac{\sqrt{2}}{3} \sin \theta_W N_{k1} + \sqrt{2} \left( \frac{1}{2} - \frac{1}{3} \sin^2 \theta_W \right) \frac{N_{k2}}{\cos \theta_W}, \\ h_{Rk}^b &= -Y_b (N_{k3} \cos \beta + N_{k4} \sin \beta), & f_{Rk}^b &= \frac{\sqrt{2}}{3} \sin \theta_W (\tan \theta_W N_{k2} - N_{k1}), \end{aligned} \quad (155)$$

$$\begin{aligned} h_{Lk}^\tau &= -Y_\tau (N_{k3} \cos \beta + N_{k4} \sin \beta), & f_{Lk}^\tau &= \sqrt{2} \sin \theta_W N_{k1} + \sqrt{2} \left( \frac{1}{2} - \sin^2 \theta_W \right) \frac{N_{k2}}{\cos \theta_W}, \\ h_{Rk}^\tau &= -Y_\tau (N_{k3} \cos \beta + N_{k4} \sin \beta), & f_{Rk}^\tau &= \sqrt{2} \sin \theta_W (\tan \theta_W N_{k2} - N_{k1}), \end{aligned} \quad (156)$$

for the sfermion-fermion-neutralino interaction, and

$$\begin{aligned} l_{1j}^t &= -V_{j1} \cos \theta_{\tilde{t}} + Y_t V_{j2} \sin \theta_{\tilde{t}}, & k_{1j}^t &= Y_b U_{j2} \cos \theta_{\tilde{t}}, \\ l_{2j}^t &= V_{j1} \sin \theta_{\tilde{t}} + Y_t V_{j2} \cos \theta_{\tilde{t}}, & k_{2j}^t &= -Y_b U_{j2} \sin \theta_{\tilde{t}}, \end{aligned} \quad (157)$$

$$\begin{aligned} l_{1j}^b &= -U_{j1} \cos \theta_{\tilde{b}} + Y_b U_{j2} \sin \theta_{\tilde{b}}, & k_{1j}^b &= Y_t V_{j2} \cos \theta_{\tilde{b}}, \\ l_{2j}^b &= U_{j1} \sin \theta_{\tilde{b}} + Y_b U_{j2} \cos \theta_{\tilde{b}}, & k_{2j}^b &= -Y_t V_{j2} \sin \theta_{\tilde{b}}, \end{aligned} \quad (158)$$

$$\begin{aligned} l_{1j}^\tau &= -U_{j1} \cos \theta_{\tilde{\tau}} + Y_\tau U_{j2} \sin \theta_{\tilde{\tau}}, & k_{1j}^\tau &= 0, \\ l_{2j}^\tau &= U_{j1} \sin \theta_{\tilde{\tau}} + Y_\tau U_{j2} \cos \theta_{\tilde{\tau}}, & k_{2j}^\tau &= 0, \end{aligned} \quad (159)$$

for the sfermion-fermion-chargino interaction.

$Y_f$  denote the Yukawa couplings:

$$Y_t = m_t/(\sqrt{2} m_W \sin \beta), \quad Y_b = m_b/(\sqrt{2} m_W \cos \beta), \quad Y_\tau = m_\tau/(\sqrt{2} m_W \cos \beta). \quad (160)$$

For the first two generations the Yukawa couplings and the mixing are negligible.

For the decay rate of the process  $\tilde{t} \rightarrow c \tilde{\chi}^0$  we use:

$$\Gamma(\tilde{t}^{L,R} \rightarrow c + \tilde{\chi}_i^0) = 3 \cdot 10^{-10} m_{\tilde{t}}^{L,R} \left( 1 - \frac{m_{\chi_o}^2}{(m_{\tilde{t}}^{L,R})^2} \right)^2 \quad (161)$$

## C.6 Two Body Decays of Sparticles to the Gravitino

The decay width of the neutralinos to the Gravitino can be written as [21]

$$\Gamma(\tilde{\chi}_i^0 \rightarrow \gamma \tilde{G}) = \frac{\kappa_{i\gamma}}{8\pi} \frac{m_{\tilde{\chi}_i^0}^5}{\Lambda_S^4} \quad (162)$$

$$\Gamma(\tilde{\chi}_i^0 \rightarrow Z \tilde{G}) = \frac{2\kappa_{iZ_T} + \kappa_{iZ_L}}{16\pi} \frac{m_{\tilde{\chi}_i^0}^5}{\Lambda_S^4} \left(1 - \frac{m_Z^2}{m_{\tilde{\chi}_i^0}^2}\right)^4 \quad (163)$$

$$\Gamma(\tilde{\chi}_i^0 \rightarrow \varphi \tilde{G}) = \frac{\kappa_{i\varphi}}{16\pi} \frac{m_{\tilde{\chi}_i^0}^5}{\Lambda_S^4} \left(1 - \frac{m_\varphi^2}{m_{\tilde{\chi}_i^0}^2}\right)^4 \quad (164)$$

where

$$\begin{aligned} \kappa_{i\gamma} &= |N'_{i1} \cos \theta_W + N'_{i2} \sin \theta_W|^2 \\ \kappa_{iZ_T} &= |N'_{i1} \sin \theta_W - N'_{i2} \cos \theta_W|^2 \\ \kappa_{iZ_L} &= |N'_{i3} \cos \beta - N'_{i4} \sin \beta|^2 \\ \kappa_{ih^0} &= |N'_{i3} \sin \alpha - N'_{i4} \cos \alpha|^2 \\ \kappa_{iH^0} &= |N'_{i3} \cos \alpha + N'_{i4} \sin \alpha|^2 \\ \kappa_{iA^0} &= |N'_{i3} \sin \beta + N'_{i4} \cos \beta|^2 \end{aligned} \quad (165)$$

and  $\varphi = (h^0, H^0, A^0)$  is any of the neutral Higgs scalar bosons. The couplings  $N'_{ij}$  are given in Eq. (40). The chargino decay widths into gravitino final states are given by

$$\Gamma(\tilde{\chi}_i^+ \rightarrow W^+ \tilde{G}) = \frac{2\kappa_{iW_T} + \kappa_{iW_L}}{16\pi} \frac{m_{\tilde{\chi}_i^+}^5}{\Lambda_S^4} \left(1 - \frac{m_W^2}{m_{\tilde{\chi}_i^+}^2}\right)^4 \quad (166)$$

$$\Gamma(\tilde{\chi}_i^+ \rightarrow H^+ \tilde{G}) = \frac{\kappa_{iH^+}}{16\pi} \frac{m_{\tilde{\chi}_i^+}^5}{\Lambda_S^4} \left(1 - \frac{m_{H^+}^2}{m_{\tilde{\chi}_i^+}^2}\right)^4 \quad (167)$$

with

$$\begin{aligned} \kappa_{iW_T} &= \frac{1}{2} (|V_{i1}|^2 + |U_{i1}|^2) \\ \kappa_{iW_L} &= |V_{i2}|^2 \sin^2 \beta + |U_{i2}|^2 \cos^2 \beta \\ \kappa_{iH^+} &= |V_{i2}|^2 \cos^2 \beta + |U_{i2}|^2 \sin^2 \beta \end{aligned} \quad (168)$$

and the widths of the 2-body slepton decays into gravitinos are given by

$$\Gamma(\tilde{f} \rightarrow f \tilde{G}) = \frac{m_{\tilde{f}}^5}{8\pi \Lambda_S^4} \quad (169)$$

## C.7 $R_p$ violating two body decays

For the  $R_p$  violating Yukawa coupling  $\lambda''_{ijk}$  the decay rate of a squark  $\tilde{q}_1$  of flavour  $i$  into the final states  $\tilde{q}_{1i} \rightarrow \bar{q}_j \bar{q}_k$  is given by

$$\Gamma(\tilde{q}_{1i} \rightarrow \bar{q}_j \bar{q}_k) = \frac{\lambda''_{ijk}{}^2 \sin^2 \theta_{\tilde{q}} |p_i|}{8\pi M_{\tilde{q}_{1i}}} 2(p_j \cdot p_k) \quad (170)$$

where  $\theta_{\tilde{q}}$  is the mixing angle of the squarks  $\tilde{q}_{Li}, \tilde{q}_{Ri}$  which form the mass eigenstates  $\tilde{q}_{1i}, \tilde{q}_{2i}$ . Here

$$\begin{aligned} |p_i| &= ((M_{\tilde{q}_{1i}}^2 - (M_{qj} + M_{qk})^2)(M_{\tilde{q}_{1i}}^2 - (M_{qj} - M_{qk})^2))^{\frac{1}{2}} / (2M_{\tilde{q}_{1i}}) \\ (p_j \cdot p_k) &= ((M_{qj}^2 + |p_i|^2)(M_{qk}^2 + |p_i|^2))^{\frac{1}{2}} + |p_i|^2 \end{aligned} \quad (171)$$

The decay rate for  $\tilde{q}_{2i} \rightarrow \tilde{q}_j \tilde{q}_k$  can be simply obtained from the above formula by replacing  $\sin \theta_{\tilde{q}} \rightarrow \cos \theta_{\tilde{q}}$  and  $\tilde{q}_{1i} \rightarrow \tilde{q}_{2i}$ . The decay rates for the other operators are analogous, except that the mixing term  $\sin \theta$  has to be replaced by  $\cos \theta$  for those sfermions which are part of the SU(2) doublet superfields (the  $L_{i,j}$  and  $Q_j$  fields in Eq. (1)). Note also that the result has to be multiplied by a colour factor  $c_f = 3$  for the slepton decays via  $L_i Q_j \bar{D}_k$ .

### C.8 $R_p$ violating three body decays

Neutralinos can decay through  $R_p$  violating couplings to SM particles via Eq. (29)-(31). The Matrix element squared for the decay  $\tilde{\chi}_l^0 \rightarrow e_i u_j \bar{d}_k$  of the operator  $L_i Q_j \bar{D}_k$  is given by [22]:

$$\begin{aligned} |\mathcal{M}(\tilde{\chi}_l^0 \rightarrow e_i u_j \bar{d}_k)|^2 &= 8c_f g^2 \lambda_{ijl}^{\prime 2} \{ \\ &D(\tilde{u}_j)^2 e_i \cdot d_k \quad [(a(u_j)^2 + b(u)^2) \tilde{\chi}_l^0 \cdot u_j + 2a(u_j)b(u)m_{u_j} M_{\tilde{\chi}_l^0}] \\ &+ D(\tilde{d}_k)^2 e_i \cdot u_j \quad [(a(d_k)^2 + b(\bar{d})^2) \tilde{\chi}_l^0 \cdot d_k - 2a(d_k)b(\bar{d})m_{d_k} M_{\tilde{\chi}_l^0}] \\ &+ D(\tilde{e}_i)^2 u_j \cdot d_k \quad [(a(e_i)^2 + b(e)^2) \tilde{\chi}_l^0 \cdot e_i + 2a(e_i)b(e)m_{e_i} M_{\tilde{\chi}_l^0}] \\ &- D(\tilde{e}_i)D(\tilde{u}_j) \quad [a(u_j)a(e_i)m_{e_i}m_{u_j}\tilde{\chi}_l^0 \cdot d_k + a(u_j)b(e)m_{u_j} M_{\tilde{\chi}_l^0} e_i \cdot d_k \\ &\quad + a(e_i)b(u)m_{e_i} M_{\tilde{\chi}_l^0} u_j \cdot d_k + b(e)b(u) \mathcal{G}(u_j, \tilde{\chi}_l^0, e_i, d_k)] \\ &- D(\tilde{u}_j)D(\tilde{d}_k) \quad [a(u_j)a(d_k)m_{u_j}m_{d_k}\tilde{\chi}_l^0 \cdot e_i - a(u_j)b(\bar{d})m_{u_j} M_{\tilde{\chi}_l^0} e_i \cdot d_k \\ &\quad + a(d_k)b(u)m_{d_k} M_{\tilde{\chi}_l^0} e_i \cdot u_j - b(u)b(\bar{d}) \mathcal{G}(u_j, \tilde{\chi}_l^0, d_k, e_i)] \\ &- D(\tilde{e}_i)D(\tilde{d}_k) \quad [-a(e_i)b(\bar{d})m_{e_i} M_{\tilde{\chi}_l^0} u_j \cdot d_k + a(e_i)a(d_k)m_{e_i}m_{d_k}\tilde{\chi}_l^0 \cdot u_j \\ &\quad + a(d_k)b(e)m_{d_k} M_{\tilde{\chi}_l^0} e_i \cdot u_j - b(e)b(\bar{d}) \mathcal{G}(\tilde{\chi}_l^0, e_i, u_j, d_k)] \} \end{aligned} \quad (172)$$

where the function  $\mathcal{G}(a, b, c, d) = (a \cdot b)(c \cdot d) - (a \cdot c)(b \cdot d) + (a \cdot d)(b \cdot c)$ . Here  $c_f = 3$  is the colour factor and  $g$  is the weak coupling constant  $g = \frac{e}{\sin \theta_w}$ . We have denoted the 4-momenta of the initial and final state particles by their particle symbols. The functions  $D(p_i)$  denote the propagators squared for particle  $p_i$  and are given by

$$D(\tilde{p}_i)^{-1} = M_{\tilde{\chi}_l^0}^2 + m_{p_i}^2 - 2\tilde{\chi}_l^0 \cdot p_i - \tilde{m}_{p_i}^2. \quad (173)$$

The coupling constants  $a(p_i), b(p)$  are given in Table 10.

The amplitude squared of the decay to the neutrino,  $\tilde{\chi}_l^0 \rightarrow \nu_i d_j \bar{d}_k$ , can be obtained from the above result by a set of simple transformations of the 4-momenta, the propagator functions  $D$  and the couplings  $a(p_i), b(p) : e_i \rightarrow \nu_i, u_j \rightarrow d_j$ .

The result for the operators  $L_i L_j \bar{E}_k$  is completely analogous, except the colour factor  $c_f = 1$ . The matrix element squared for the operator  $\bar{U}_i \bar{D}_j \bar{D}_k$  is

$$\begin{aligned} |\mathcal{M}(\tilde{\chi}_l^0 \rightarrow \bar{u}_i \bar{d}_j \bar{d}_k)|^2 &= 8c_f g^2 \lambda^{\prime \prime 2} \{ \\ &D(\tilde{u}_i)^2 \bar{d}_j \cdot \bar{d}_k \quad [(b(u)^2 + a(u_i)^2) \tilde{\chi}_l^0 \cdot \bar{u}_i - 2b(u)a(u_i)m_{u_i} M_{\tilde{\chi}_l^0}] \end{aligned} \quad (174)$$

	$a(p_i)$	$b(p_i)$
$e_i$	$\frac{N'_{3l}}{2M_W \cos \beta} m_{e_i}$	$-\frac{1}{2}(N'_{2l} + \tan \theta_W N'_{1l})$
$\bar{e}_i$	$\frac{N'_{3l}}{2M_W \cos \beta} m_{e_i}$	$-\tan \theta_W N'_{1l}$
$\nu_i$	0	$\frac{1}{2}(N'_{2l} - \tan \theta_W N'_{1l})$
$u_i$	$\frac{N'_{4l}}{2M_W \sin \beta} m_{u_j}$	$\frac{1}{2}(N'_{2l} + \frac{1}{3} \tan \theta_W N'_{1l})$
$\bar{u}_i$	$\frac{N'_{4l}}{2M_W \sin \beta} m_{u_j}$	$\frac{2}{3} \tan \theta_W N'_{1l}$
$d_i$	$\frac{N'_{3l}}{2M_W \cos \beta} m_{d_k}$	$-\frac{1}{2}(N'_{2l} - \frac{1}{3} \tan \theta_W N'_{1l})$
$\bar{d}_i$	$\frac{N'_{3l}}{2M_W \cos \beta} m_{d_k}$	$-\frac{1}{3} \tan \theta_W N'_{1l}$

Table 10: The Coupling constants  $a(p_i)$  and  $b(p)$  used in the LSP decay calculation for a neutralino  $\tilde{\chi}_l^0$ .

$$\begin{aligned}
& +D(\tilde{d}_j)^2 \bar{u}_i \cdot \bar{d}_k \quad [(a(d_j)^2 + b(d)^2) \tilde{\chi}_l^0 \cdot \bar{d}_j - 2b(d)a(d_j)m_{d_j}M_{\tilde{\chi}_l^0}] \\
& +D(\tilde{d}_k)^2 \bar{u}_i \cdot \bar{d}_j \quad [(a(\bar{d}_k)^2 + b(\bar{d})^2) \tilde{\chi}_l^0 \cdot \bar{d}_k - 2b(\bar{d})a(\bar{d}_k)m_{d_k}M_{\tilde{\chi}_l^0}] \\
& +D(\tilde{u}_i)D(\tilde{d}_k) \quad [a(\bar{u}_i)a(\bar{d}_j) \mathcal{G}(\bar{u}_i, \tilde{\chi}_l^0, \bar{d}_j, \bar{d}_k) + b(\bar{u})b(\bar{d})m_{u_i}m_{d_k}\tilde{\chi}_l^0 \cdot \bar{d}_k \\
& \quad - b(\bar{u})a(\bar{d}_j)m_{u_i}M_{\tilde{\chi}_l^0}\bar{d}_j \cdot \bar{d}_k - b(\bar{d})a(\bar{u}_i)m_{d_j}M_{\tilde{\chi}_l^0}\bar{u}_i \cdot \bar{d}_k] \\
& +D(\tilde{u}_i)D(\tilde{d}_k) \quad [a(\bar{u}_i)a(\bar{d}_k) \mathcal{G}(u_i, \tilde{\chi}_l^0, d_k, d_j) + b(\bar{u})b(\bar{d})m_{u_i}m_{d_k}\tilde{\chi}_l^0 \cdot \bar{d}_j \\
& \quad - b(\bar{u})a(\bar{d}_k)m_{u_i}M_{\tilde{\chi}_l^0}\bar{d}_j \cdot \bar{d}_k - b(\bar{d})a(\bar{u}_i)m_{d_k}M_{\tilde{\chi}_l^0}\bar{u}_i \cdot \bar{d}_j] \\
& +D(\tilde{d}_j)D(\tilde{d}_k) \quad [a(\bar{d}_j)a(\bar{d}_k) \mathcal{G}(d_j, \tilde{\chi}_l^0, d_k, u_i) + b(\bar{d})b(\bar{d})m_{d_j}m_{d_k}\tilde{\chi}_l^0 \cdot \bar{u}_i \\
& \quad - b(\bar{d})a(\bar{d}_k)m_{d_j}M_{\tilde{\chi}_l^0}\bar{u}_i \cdot \bar{d}_k - b(\bar{d})a(\bar{d}_j)m_{d_k}M_{\tilde{\chi}_l^0}\bar{u}_i \cdot \bar{d}_j] \Big\}
\end{aligned}$$

Here the colour factor  $c_f = 6$ . The partial decay rates for the neutralino decay modes is then given by

$$\begin{aligned}
\Gamma_{\tilde{\chi}_l^0}(LL\bar{E}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^0}} (2|\mathcal{M}(\tilde{\chi}_l^0 \rightarrow e_i \bar{\nu}_j \bar{e}_k)|^2 + 2|\mathcal{M}(\tilde{\chi}_l^0 \rightarrow \bar{\nu}_i e_j \bar{e}_k)|^2) dE_i dE_j \\
\Gamma_{\tilde{\chi}_l^0}(LQ\bar{D}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^0}} (2|\mathcal{M}(\tilde{\chi}_l^0 \rightarrow e_i u_j \bar{d}_k)|^2 + 2|\mathcal{M}(\tilde{\chi}_l^0 \rightarrow \nu_i d_j \bar{d}_k)|^2) dE_i dE_j \\
\Gamma_{\tilde{\chi}_l^0}(\bar{U}\bar{D}\bar{D}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^0}} 2|\mathcal{M}(\tilde{\chi}_l^0 \rightarrow \bar{u}_i \bar{d}_j \bar{d}_k)|^2 dE_i dE_j
\end{aligned} \tag{175}$$

where the matrix element squares are multiplied by a factor of two since the LSP is a Majorana fermion and can decay to the conjugate final states.

Charginos can decay via Eq. (32)-(34), and the matrix elements squared for the  $L_i Q_j \bar{D}_k$  operator can be written as [22]:

$$\begin{aligned}
|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i u_j \bar{d}_k)|^2 &= 4c_f g^2 \lambda'^2 \left[ \frac{\alpha_R^2}{R^2(\tilde{e}_{iL})} (\tilde{\chi}_l^+ \cdot \nu_i)(u_j \cdot \bar{d}_k) \right. \\
&\quad \left. + \frac{(\nu_i \cdot \bar{d}_k)}{R^2(\tilde{d}_{jL})} \left\{ (\beta_L^2 + \beta_R^2)(\tilde{\chi}_l^+ \cdot u_j) + 2\mathcal{R}e(\beta_L \beta_R^* m_{uj} M_{\tilde{\chi}_l^+}) \right\} \right]
\end{aligned} \tag{176}$$

$$\begin{aligned}
& -\mathcal{R}e \left\{ \frac{\alpha_R}{R(\tilde{e}_{iL})R(\tilde{d}_{jL})} \left( \beta_L^* m_{uj} M_{\tilde{\chi}_l^+} (u_j \cdot \bar{d}_k) + \beta_R^* \mathcal{G}(p, \nu_i, \bar{d}_k, u_j) \right) \right\} \\
|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{d}_j d_k)|^2 &= 4c_f g^2 \lambda^2 \left[ \frac{(d_j \cdot \bar{d}_k)}{R^2(\tilde{\nu}_{iL})} \left\{ (\gamma_L^2 + \gamma_R^2)(\tilde{\chi}_l^+ \cdot e_i) + 2\mathcal{R}e(\gamma_L \gamma_R^* m_{ei} M_{\tilde{\chi}_l^+}) \right\} \right. \\
& + \frac{(e_i \cdot \bar{d}_k)}{R^2(\tilde{u}_{jL})} \left\{ (\delta_L^2 + \delta_R^2)(\tilde{\chi}_l^+ \cdot d_j) + 2\mathcal{R}e(\delta_L \delta_R^* m_{dj} M_{\tilde{\chi}_l^+}) \right\} \\
& - \frac{1}{R(\tilde{\nu}_{iL})R(\tilde{u}_{jL})} \mathcal{R}e \left\{ \gamma_L \delta_L^* \mathcal{G}(\tilde{\chi}_l^+, e_i, \bar{d}_k, d_j) + \gamma_L \delta_R^* m_{dj} M_{\tilde{\chi}_l^+} (e_i \cdot \bar{d}_k) \right. \\
& \left. \left. + \gamma_R \delta_L^* m_{ei} M_{\tilde{\chi}_l^+} (d_j \cdot \bar{d}_k) + \gamma_R \delta_R^* m_{ei} m_{dj} (\tilde{\chi}_l^+ \cdot \bar{d}_k) \right\} \right] \quad (177)
\end{aligned}$$

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{u}_j u_k)|^2 = \frac{2c_f \lambda^2 g^2 m_{dk}^2 |U_{l2}|^2}{M_W^2 \cos^2 \beta R^2(\tilde{d}_{kR})} (e_i \cdot u_j)(\tilde{\chi}_l^+ \cdot u_k) \quad (178)$$

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{\nu}_i \bar{d}_j u_k)|^2 = \frac{2c_f \lambda^2 g^2 m_{dk}^2 |U_{l2}|^2}{M_W^2 \cos^2 \beta R^2(\tilde{d}_{kR})} (\nu_i \cdot d_j)(\tilde{\chi}_l^+ \cdot u_k) \quad (179)$$

where the couplings  $\alpha_{L,R}, \beta_{L,R}, \gamma_{L,R}$  and  $\delta_{L,R}$  are

$$\begin{aligned}
\alpha_L &= 0, & \alpha_R &= -iU_{l1} \\
\beta_L &= \frac{im_{uj}V_{l2}^*}{\sqrt{2}M_W \sin \beta}, & \beta_R &= \alpha_R \\
\gamma_L &= iV_{l1}^*, & \gamma_R &= -\frac{igm_{ei}U_{l2}}{\sqrt{2}M_W \cos \beta} \\
\delta_L &= \gamma_L, & \delta_R &= -\frac{igm_{dj}U_{l2}}{\sqrt{2}M_W \cos \beta}
\end{aligned}$$

The final state momenta are denoted by the particle symbols.  $M_{\tilde{\chi}_l^+}$  is the chargino mass and  $m_{ei,dj,dk}$  are the final state fermion masses.  $c_f = 3$  is the colour factor. The propagator terms  $R(p)$  are defined by

$$\begin{aligned}
R(\tilde{e}_{iL}) &= (\chi^+ - \nu_i)^2 - \tilde{m}_{eiL}^2, & R(\tilde{d}_{jL}) &= (\chi^+ - u_j)^2 - \tilde{m}_{djL}^2, \\
R(\tilde{\nu}_{iL}) &= (\chi^+ - e_i)^2 - \tilde{m}_{\nu iL}^2, & R(\tilde{u}_{jL}) &= (\chi^+ - d_j)^2 - \tilde{m}_{ujL}^2, \\
R(\tilde{d}_{kR}) &= (\chi^+ - u_k)^2 - \tilde{m}_{dkR}^2, & R(\tilde{e}_{kR}) &= (\chi^+ - \nu_k)^2 - \tilde{m}_{ekR}^2, \\
R(\tilde{u}_{iR}) &= (\chi^+ - \bar{d}_i)^2 - \tilde{m}_{uiR}^2, & R(\tilde{d}_{jR}) &= (\chi^+ - u_j)^2 - \tilde{m}_{djR}^2.
\end{aligned}$$

For the operator  $L_i L_j \bar{E}_k$  the matrix elements squared are

$$\begin{aligned}
|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i \nu_j \bar{e}_k)|^2 &= 4g^2 \lambda^2 \left[ \frac{\alpha_R^2}{R^2(\tilde{e}_{iL})} (\tilde{\chi}_l^+ \cdot \nu_i)(\nu_j \cdot \bar{e}_k) + \frac{\beta_R^2}{R^2(\tilde{e}_{jL})} (\tilde{\chi}_l^+ \cdot \nu_j)(\nu_i \cdot \bar{e}_k) \right. \\
& \left. - \mathcal{R}e \left\{ \frac{\alpha_R \beta_R^*}{R(\tilde{e}_{iL})R(\tilde{e}_{jL})} \mathcal{G}(p, \nu_i, \bar{e}_k, \nu_j) \right\} \right] \quad (180)
\end{aligned}$$

$$\begin{aligned}
|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{e}_j e_k)|^2 &= 4g^2 \lambda^2 \left[ \frac{(e_j \cdot \bar{e}_k)}{R^2(\tilde{\nu}_{iL})} \left\{ (\gamma_L^2 + \gamma_R^2)(\tilde{\chi}_l^+ \cdot e_i) + 2\mathcal{R}e(\gamma_L \gamma_R^* m_{ei} M_{\tilde{\chi}_l^+}) \right\} \right. \\
& + \frac{(e_i \cdot \bar{e}_k)}{R^2(\tilde{\nu}_{jL})} \left\{ (\delta_L^2 + \delta_R^2)(\tilde{\chi}_l^+ \cdot e_j) + 2\mathcal{R}e(\delta_L \delta_R^* m_{ej} M_{\tilde{\chi}_l^+}) \right\} \\
& - \frac{1}{R(\tilde{\nu}_{iL})R(\tilde{\nu}_{jL})} \mathcal{R}e \left\{ \gamma_L \delta_L^* \mathcal{G}(\tilde{\chi}_l^+, e_i, \bar{e}_k, e_j) + \gamma_L \delta_R^* m_{ej} M_{\tilde{\chi}_l^+} (e_i \cdot \bar{e}_k) \right. \\
& \left. \left. + \gamma_R \delta_L^* m_{ei} M_{\tilde{\chi}_l^+} (e_j \cdot \bar{e}_k) + \gamma_R \delta_R^* m_{ei} m_{ej} (\tilde{\chi}_l^+ \cdot \bar{e}_k) \right\} \right] \quad (181)
\end{aligned}$$



$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \nu_j \nu_k)|^2 = 4g^2 \lambda^2 \left[ \frac{\epsilon_R^2}{R^2(\tilde{e}_{kR})} (\tilde{\chi}_l^+ \cdot \nu_k) (\bar{e}_i \cdot \nu_j) \right] \quad (182)$$

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i \bar{e}_j \nu_k)|^2 = 4g^2 \lambda^2 \left[ \frac{\epsilon_R^2}{R^2(\tilde{e}_{kR})} (\tilde{\chi}_l^+ \cdot \nu_k) (\nu_i \cdot \bar{e}_j) \right] \quad (183)$$

where  $\alpha, \beta, \gamma, \delta$  are given as above except that in  $\delta_R$   $m_{dj}$  is replaced by  $m_{ej}$  and  $\beta_L = 0$  because of vanishing neutrino mass, and  $\epsilon_R = -\frac{igm_{ek}U_{l2}}{\sqrt{2}M_W \cos \beta}$ . For the operator  $\bar{U}\bar{D}\bar{D}$  the matrix elements squared are

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{d}_i \bar{d}_j \bar{d}_k)|^2 = 4c_f g^2 \lambda^2 \left[ \frac{\beta_R^2}{R^2(\tilde{u}_{iR})} (\tilde{\chi}^+ \cdot \bar{d}_i) (\bar{d}_j \cdot \bar{d}_k) \right] \quad (184)$$

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow u_i u_j d_k)|^2 = 4c_f g^2 \lambda^2 \left[ \frac{\gamma_R^2}{R^2(\tilde{d}_{jR})} (\tilde{\chi}^+ \cdot u_j) (u_i \cdot d_k) \right] \quad (185)$$

$$|\mathcal{M}(\tilde{\chi}_l^+ \rightarrow u_i d_j u_k)|^2 = 4c_f g^2 \lambda^2 \left[ \frac{\delta_R^2}{R^2(\tilde{d}_{kR})} (\tilde{\chi}^+ \cdot u_k) (u_i \cdot d_j) \right] \quad (186)$$

$\beta_R, \gamma_R, \delta_R$  are given by

$$\begin{aligned} \beta_R &= -\frac{im_{ui}V_{l2}^*}{\sqrt{2}M_W \sin \beta}, \quad \gamma_R = -\frac{igm_{dj}U_{l2}}{\sqrt{2}M_W \cos \beta} \\ \delta_R &= -\frac{igm_{dk}U_{l2}}{\sqrt{2}M_W \cos \beta} \end{aligned} \quad (187)$$

and the colour factor  $c_f = 6$ . The partial decay rate for these modes is then given by

$$\begin{aligned} \Gamma_{\tilde{\chi}_l^+}(LL\bar{E}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^+}} ( |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i \nu_j \bar{e}_k)|^2 + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{e}_j e_k)|^2 + \\ \Gamma_{\tilde{\chi}_l^+}(LQ\bar{D}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^+}} ( |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \nu_j \nu_k)|^2 + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i \bar{e}_j \nu_k)|^2 ) dE_i dE_j \\ &\quad + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \nu_i u_j \bar{d}_k)|^2 + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{d}_j d_k)|^2 + \\ \Gamma_{\tilde{\chi}_l^+}(\bar{U}\bar{D}\bar{D}) &= \int \frac{1}{2\pi^3} \frac{1}{16M_{\tilde{\chi}_l^+}} ( |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{e}_i \bar{u}_j u_k)|^2 + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{\nu}_i \bar{d}_j u_k)|^2 ) dE_i dE_j \\ &\quad + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow \bar{d}_i \bar{d}_j \bar{d}_k)|^2 + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow u_i u_j d_k)|^2 + \\ &\quad + |\mathcal{M}(\tilde{\chi}_l^+ \rightarrow u_i d_j u_k)|^2 ) dE_i dE_j \end{aligned} \quad (188)$$

## D Common Blocks

In the following the common blocks are listed in alphabetical order.

- COMMON/ CHAMIX/ OIJL(2,2), OIJR(2,2), V(2,2), U(2,2), FM(2), ETA(2)
- COMMON/ CHANEU/ OIJLP(4,2), OIJRP(4,2)
  - OIJL, OIJR** : chargino couplings to Z.
  - V, U** : diagonalising matrices of chargino..
  - FM** : positive chargino masses.
  - ETA** : sign of diagonal values.
  - OIJLP, OIJRP** : chargino couplings to neutralinos.
- COMMON/ CONST/ IDBG, IGENER, IRAD, FRAD: (Input cards DEBUG, GENER, ISR and FSR)
- COMMON/ COUPLS/ A,B: Coupling constants used in the  $R_p$  violating gaugino decay calculation.
- COMMON/ DECSEL/ IDECSEL(23),IPROCSEL(11): (Input cards DECSEL,PROCSEL)
- COMMON/ DOTPROD/PP: Dot-products used in the  $R_p$  violating gaugino decay calculation.
- COMMON/ FINDEX/ FMPR1, FMPR2, XCROST, APRO
  - FMPR1, FMPR2** : masses of the 2 current produced sparticles.
  - XCROST** : current cross section.
  - APRO** : maximum differential amplitude.
- COMMON/ GAUG2BDECS/ IJKGAUG(MAXGAUG2BODDECS,3),NGAUG
- COMMON/ GAUG2BDECS2/ GIJKGAUG(MAXGAUG2BODDECS)
  - NGAUG** : Number of  $R_p$  conserving 2-body gaugino decay modes.
  - IJKGAUG(n,i)** : i=1...3 gives the initial(i=1) and final state particles (i=2-3) in the 2-body decay.
  - GIJKGAUG** : Width of 2-particle decay.
- COMMON/ GAUGM/ MASSNEU,MASSCHA : Neutralino and chargino mass used in current  $R_p$  violating gaugino calculation.
- COMMON/ HABKANE/XM(i,j) : Mixing matrix  $N'_{ij}$  defined by Eq. (40).
- COMMON/ HIGGSES/MLH,MA,MHH,MHPM,SINA,COSA : Higgs masses and mixing angles.
- COMMON/ INDEXX/ INDEX, INDEX1, INDEX2, NEVT
  - INDEX** is an internal variable determining whether the program currently processes neutralino (INDEX=1), chargino (INDEX=2) sfermion (INDEX=3), gravitino (INDEX=4), single sparticle production (INDEX=5), or Higgs (INDEX=5).
  - INDEX1, INDEX2** are the index code of the specific type of 2 sparticles produced.
- COMMON/ INDICES/I,IJ,IJC,IJF,IJF\_MIX
  - I(4)** : Input Card INDIC
  - IJ(i=1..3,j=1..4)** : Decay product(i) of  $R_p$  violating neutralino(j) decay.
  - IJC(i=1..3,j=1..2)** : Decay product(i) of  $R_p$  violating chargino(j) decay.
  - IJF(n=1..68,c=1..2,fs=1..2)** : Decay products of direct  $R_p$  violating sfermion decays. n=left-handed sfermion decaying into the final state fs=1..2. There are up to c=1..2 decay modes.

- IJF\_MIX** : Same as IJF, except that the n=right-handed sfermion.
- COMMON/ ISR/ QK(4) (4-vector of ISR  $\gamma$ ).
- COMMON/ KINEM/ FLUM, ECM, S, ROOTS, T, Q, Q2, EN(2)  
**FLUM, ECM, S, ROOTS** :  $L, E_{CM}, s, \sqrt{s}$  (  $L$  is the luminosity,  $E_{CM}$  is the nominal energy,  $s$  and  $\sqrt{s}$  change when initial state radiation is permitted).  
**T, Q, Q2, EN** :  $t, q, q^2$  and energies of 2 products.
- COMMON/ LAMDA/XLAMA :  $R_p$  violating coupling strength  $\lambda$ .
- COMMON/ LIFE/LIFETIME : Input Card LIFE.
- COMMON/ LSUSY/XLSUSY : Spontaneous Supersymmetry breaking scale  $\lambda_{SUSY}$ . Used to calculate the mass of the gravitino.
- COMMON/ LUSHOWERS/LISTQMX
- COMMON/ LUSHOWERS2/LISTSHOWERIND,NSHOWERS  
**LISTQMX(i),LISTSHOWERIND(i,j)** : Give the invariant mass and the index of the particles(j) of the i-th shower which are to be processed by JETSET routine LUSHOW.  
**NSHOWERS** : Number of showers to process.
- COMMON/ MDS/MODES,MIX : Input Cards MODES and MIX.
- COMMON/ MSSM/ TANB, SINB, COSB, FMGAUG, FMR, FM0, ATRI(3)  
**TANB, SINB, COSB** :  $\tan \beta = v_2/v_1$ .  
**FMGAUG** :  $M_2$  gaugino mass.  
**FMR** : Higgs mixing term  $\mu$ .  
**FM0** : common scalar mass  $m_0$ .  
**ATRI** : 3 trilinear couplings for stop, sbottom and stau respectively.
- COMMON/ NEUMIX/ ZR(4,4), WAS(4), ESA(4), VOI JL(4,4), VOI JR(4,4), GFIR(4,4), GFIL(4,4)  
**ZR** : neutralino diagonalising matrix.  
**ESA** : phase factors of eigenvalues .  
**WAS** : absolute masses in ascending order.  
**VOI JL, VOI JR** : neutralino couplings to Z.  
**GFIL, GFIR** : neutralino couplings to  $\tilde{u}, \tilde{d}, \tilde{\nu}, \tilde{e}$ .
- COMMON/ REORDER/ ISPA(12,2), KL(2,18), KLAP(2,18), IDECS(12,2) (Correspondence matrices for decays and equivalence with LUND)  
**ISPA** : LUND codes of left/right sfermions (18 possible).  
**KL** : standard particles accompanying a gaugino in 3-body decay .  
**KLAP** : IDs of  $t, u$  exchanged particles.  
**IDECS** : mapping of SUSYGEN standard particle convention to the LUND ones.
- COMMON/ RESA/RES,RES1A,RES2A :  
**RES** : Total Decay rate of  $R_p$  violating neutralino decay.  
**RES1A,RES2A** : Partial Decay widths of  $R_p$  violating neutralino decays to final states of type (1),(2).
- COMMON/ RKEY/rgmaum, rgmaur, rgm0, rgtanb, rgatri, rgma, rfmsq, rfmsstopl, rfmsstopr, rfmsell, rfmselr, rfmsnu, rfmglu, recm, rflum  
**rgmaum,...,rfmglu** : The single precision version of the variables in the COMMON STEER.

- recm,rflum,rvscan** : CM-Energy, Luminosity in single precision.
- **COMMON/ RPARI/ RPAR,MGM**  
**RPAR** : Logical, TRUE  $\rightarrow R_p$  is conserved.  
**MGM** : Logical, TRUE  $\rightarrow$  Gauge Mediated SUSY gravitino decays enabled.
  - **COMMON/ RWIDTHS/ GIJ,GIJC,GIJF,GIJF\_MIX** : Decay rates of the  $R_p$  violating gaugino and sfermion decays. See also **COMMON INDICES**.
  - **COMMON/ SDECAY/ DAS, DBS, DCS, DATL, DAUL, DATUL, DASTL, DBSTL, DASUL, DBSUL, DATR, DAUR, DATUR, DASTR, DBSTR, DASUR, DBSUR, XDEC(17,64)**
  - **DIMENSION CURENT(17)**
  - **EQUIVALENCE (CURENT(1),DAS)**
  - **DAS** etc correspond to the 17 variables that characterise gaugino 3-body decay. There are 64 different patterns;
    1. 6x4 neutralino-neutralino to uu, dd, vv, ll.
    2. 8x4 chargino-neutralino to ud, lv.
    3. 1x8 chargino-chargino uu,dd, vv, ll.
  - **COMMON/ SM/ FMW, FMZ, GAMMAZ, SINW, COSW, ALPHA, E2, G2, PI, TWOPI, FLC(12), FRC(12), GMS(12), ECHAR(12)**  
**FMW** : W mass (80.2GeV).  
**FMZ** : Z mass (91.19GeV).  
**GAMMAZ** : Z width (2.497GeV).  
**SINW, COSW** :  $\sin \theta_W(0.231243)$ ,  $\cos \theta_W$  Weinberg.  
**PI, ALPHA, e2, G2** :  $\pi$ ,  $\frac{1}{128}$ ,  $e^2 = 4\pi\alpha$ ,  $g^2 = \frac{e^2}{\sin^2 \theta_W}$ .  
**FLC** :  $T_3 - Q \sin^2 \theta_W$ , left SM couplings.  
**FRC** :  $-Q \sin^2 \theta_W$ , right SM couplings.  
**GMS** : masses of standard particles in the following order (up, down, neutrino, electron)  $\times 3$  for the three families.  
**ECHAR** : charge of standard particles.
  - **COMMON/ SPARC/ ZINO, WINO, SELE, SMUO, STAU, SNU, SQUA, STOPA, SBOTA** (Input cards ZINO etc)
  - **COMMON/ SPARTCL/ FMAL(12), FMAR(12), RATQA(12), FGAMC(12), FGAMCR(12), COSMI(12), FM1(12), FM2(12)**  
**FMAL(12), FMAR(12)** : Left/right masses of sparticles.  
**RATQA(12)** : charge.  
**FGAMC(12), FGAMCR(12)** : left/right coupling to Z.  
**COSMI(12)** : cosine of mixing angle ( $\cos \phi$ ).  
**FM1(12), FM2(12)** : masses of the 1,2 combinations for the 12 sfermions.  
 All the above are in the following order:  $\tilde{u}, \tilde{d}, \tilde{\nu}, \tilde{e} \times 3$  generations.
  - **COMMON/ SSCALE/ RSCALE** : Input Cards RS.
  - **COMMON/ SSMODE/ NSSMOD, ISSMOD(MXSS), JSSMOD(5,MXSS)**
  - **COMMON/ SSMOD1/ GSSMOD(MXSS), BSSMOD(MXSS)** (ISAJET type commons, for comparison)

**MXSS** : maximum number of modes.

**NSSMOD** : number of modes.

**ISSMOD** : initial particle.

**JSSMOD** : final particles.

**GSSMOD** : width.

**BSSMOD** : branching ratio.

- COMMON/ STEER/ GMAUM, GMAUR, GM0, GTANB, GATRI, FMSQ, FMSTOPL, FMSTOPR, FMSELL, FMSELR, FMSNU, FMGLU  
( $M, \mu, m_0, \tan\beta, A, m_{\tilde{q}}, m_{\tilde{t}_L}, m_{\tilde{t}_R}, m_{\tilde{e}_L}, m_{\tilde{e}_R}, m_{\tilde{\nu}}, m_{\tilde{g}}$ )
- COMMON/ STOPMIX/STOP1,SBOT1,STAU1,STOP2,SBOT2,STAU2, PHIMIX1,PHIMIX2,PHIMIX3  
: Input cards MASMX
- COMMON/ STR/ WRT, SCAN, LEPI (Input cards LUWRIT, SCAN, LEPI)
- COMMON/ SUSY/TANTHW,COSB,SINB :  $\tan\theta_W, \cos\beta, \sin\beta$ , where  $\beta$  is the ratio of the neutral Higgs vevs.
- COMMON/ TWOBODIES/ TWOB : Input cards TWOB
- COMMON/ UBRA/ NDECA(-80:80)  
**NDECA** : number of decay nodes open to the particle with corresponding ID.
- COMMON/ UBRA1/ BRTOT(2, 50, -80:80)  
**BRTOT** : i)pointer to SSMODE, ii)integrated branching ratios.
- COMMON/ WIDTHS/ GW, WIDFL(12), WIDFR(12), FMELTW, FMERTW, FMELUW, FMERUW, LINDA(18,6,6)  
**GW** : The product of Z (or W) mass and width ( $GeV^2$ ).  
**WIDFL, WIDFR** : Sparticle widths (GeV).  
**FMELTW/FMERTW, FMELUW/FMERUW** : The products of sparticle masses and widths ( $GeV^2$ ).  
**LINDA** : (Internal use).
- COMMON/ VARIABLES/ FMS, FMI, FMK, FML1, FML2, ETAI, ETAK, BRSPA(6,48), LIND(6,6,6), BRGAUG(23,6,6), FMELT, FMERT, FMELU, FMERU  
All variables relate to the R-parity conserving gaugino decays except for BRSPA, which relates to the R-parity conserving sfermion decays.  
**FMS** : is the s channel exchanged particle W or Z.  
**FMI, ETAI** : is the mass, $\eta$  of the father.  
**FMK, ETAK**, : is the mass, $\eta$  of the son.  
**FML1, FML2** : are the accompanying partons.  
**FMELT/FELU, FMERT/FMERU** : are the sparticles exchanged in  $u, t$  channels.
  - LIND(i, j, k) are the permitted transitions;  
**i** : is one of the 6 patterns uu, dd, ll, vv, ud, lv.  
**j** : is one of the son gauginos.  
**k** : is one of the father gauginos.
  - BRGAUG(i, j, k) are the integrated differential widths;  
**i** : is one of the 18 patterns (uu, dd, vv, ll, ud, lv)  $\times 3$  generations.

- j** : is one of the son gauginos.
  - k** : is one of the father gauginos.
  - BRSPA(i,j) are the partial sparticle widths;
  - i** : is the index of the daughter gaugino.
  - j** : is the index of the father sfermion.
- COMMON/ XCROS/ XGAUG(8), XETA(8)
  - XGAUG** are the masses of the 4 neutralinos and the 2 charginos  $\chi_{1,2}^{\pm}$ .
  - XETA** the  $\eta = \pm 1$  phase factors.

## E Ntuple variables

Variable	Description	Variable	Description	Variable	Description
fECM	$\sqrt{s}$	fM2	$M_2$	fmu	$\mu$
fm0	$m_0$	ftanb	$\tan \beta$	fA	$A_t$
fmA	$m_A$				

Table 11: Input parameters - block “COL1”.

Variable	Description	Variable	Description	Variable	Description
fx01	$M(\chi_1^0)$	fx02	$M(\chi_2^0)$	fx03	$M(\chi_3^0)$
fx04	$M(\chi_4^0)$	fx1p	$M(\chi_1^+)$	fx2p	$M(\chi_2^+)$
fupl	$M(\tilde{u}_L)$	fdownl	$M(\tilde{d}_L)$	fneu	$M(\tilde{\nu})$
fel	$M(\tilde{e}_L)$	fupr	$M(\tilde{u}_R)$	fdownr	$M(\tilde{d}_R)$
fer	$M(\tilde{e}_R)$	ftop1	$M(\tilde{t}_1)$	fbot1	$M(\tilde{b}_1)$
ftau1	$M(\tilde{\tau}_1)$	ftop2	$M(\tilde{t}_2)$	fbot2	$M(\tilde{b}_2)$
ftau2	$M(\tilde{\tau}_2)$	fmh1	$M(h)$	fmh2	$M(H)$
fmhpc	$M(H^\pm)$				

Table 12: Masses - block “COL1”.

Variable	Description	Variable	Description	Variable	Description
zx01a	$N_{11}$	zx01b	$N_{21}$	zx01c	$N_{31}$
zx01d	$N_{41}$	zx02a	$N_{12}$	zx02b	$N_{22}$
zx02c	$N_{32}$	zx02d	$N_{42}$	zx03a	$N_{13}$
zx03b	$N_{23}$	zx03c	$N_{33}$	zx03d	$N_{43}$
zx04a	$N_{14}$	zx04b	$N_{24}$	zx04c	$N_{34}$
zx04d	$N_{44}$	u11	$U_{11}$	u12	$U_{12}$
v11	$V_{11}$	v12	$V_{12}$		

Table 13: Neutralino/Chargino eigenvectors - block “COL3”.

Variable	Description	Variable	Description	Variable	Description
sx1x1	$\sigma(\chi_1^0\chi_1^0)$	sx1x2	$\sigma(\chi_1^0\chi_2^0)$	sx2x2	$\sigma(\chi_2^0\chi_2^0)$
sx1x3	$\sigma(\chi_1^0\chi_3^0)$	sx2x3	$\sigma(\chi_2^0\chi_3^0)$	sx3x3	$\sigma(\chi_3^0\chi_3^0)$
sx1x4	$\sigma(\chi_1^0\chi_4^0)$	sx2x4	$\sigma(\chi_2^0\chi_4^0)$	sx3x4	$\sigma(\chi_3^0\chi_4^0)$
sx4x4	$\sigma(\chi_4^0\chi_4^0)$	sx1x1p	$\sigma(\chi_1^+\chi_1^+)$	sx1x2p	$\sigma(\chi_1^+\chi_2^+)$
sx2x2p	$\sigma(\chi_2^+\chi_2^+)$	snue	$\sigma(\tilde{\nu}_e\tilde{\nu}_e)$	snutot	$\sigma(\tilde{\nu}_e\tilde{\nu}_e) + \sigma(\tilde{\nu}_\mu\tilde{\nu}_\mu)$ $+ \sigma(\tilde{\nu}_\tau\tilde{\nu}_\tau)$
ssel	$\sigma(\tilde{e}_L\tilde{e}_L)$	sser	$\sigma(\tilde{e}_R\tilde{e}_R)$	sselser	$\sigma(\tilde{e}_L\tilde{e}_R)$
smul	$\sigma(\tilde{\mu}_L\tilde{\mu}_L)$	smur	$\sigma(\tilde{\mu}_R\tilde{\mu}_R)$	stau1	$\sigma(\tilde{\tau}_1\tilde{\tau}_1)$
stau2	$\sigma(\tilde{\tau}_2\tilde{\tau}_2)$	sbt1	$\sigma(\tilde{b}_1\tilde{b}_1)$	sbt2	$\sigma(\tilde{b}_2\tilde{b}_2)$
stp1	$\sigma(\tilde{t}_1\tilde{t}_1)$	stp2	$\sigma(\tilde{t}_2\tilde{t}_2)$	sqr	$\sum_{i=1}^4 \sigma(\tilde{q}_L^i\tilde{q}_L^i) + \sigma(\tilde{q}_R^i\tilde{q}_R^i)$
sgx1	$\sigma(\chi_1^0\tilde{G})$	sgx2	$\sigma(\chi_2^0\tilde{G})$	sgx3	$\sigma(\chi_3^0\tilde{G})$
sgx4	$\sigma(\chi_4^0\tilde{G})$	srpvx1	$\sigma(\chi_1^0\nu)$	srpvx2	$\sigma(\chi_2^0\nu)$
srpvx3	$\sigma(\chi_3^0\nu)$	srpvx4	$\sigma(\chi_4^0\nu)$	srpvx1p	$\sigma(\chi_1^+l^-)$
srpvx2p	$\sigma(\chi_2^+l^-)$	szh1	$\sigma(hZ)$	szh2	$\sigma(HZ)$
sah1	$\sigma(hA)$	sah2	$\sigma(HA)$	shphp	$\sigma(H^+H^-)$

Table 14: Cross sections in pb - block “COL2”.

Variable	Description	Variable	Description	Variable	Description
sx01	$\Gamma_{R_p}(\chi_1^0)$	sx02	$\Gamma_{R_p}(\chi_2^0)$	sx03	$\Gamma_{R_p}(\chi_3^0)$
sx04	$\Gamma_{R_p}(\chi_4^0)$	sxp1	$\Gamma_{R_p}(\chi_1^+)$	sxp2	$\Gamma_{R_p}(\chi_2^+)$
sul	$\Gamma_{R_p}(\tilde{u}_L)$	sdl	$\Gamma_{R_p}(\tilde{d}_L)$	snel	$\Gamma_{R_p}(\tilde{\nu}_e)$
sel	$\Gamma_{R_p}(\tilde{e}_L)$	scl	$\Gamma_{R_p}(\tilde{c}_L)$	ssl	$\Gamma_{R_p}(\tilde{s}_L)$
snmel	$\Gamma_{R_p}(\tilde{\nu}_\mu)$	sml	$\Gamma_{R_p}(\tilde{\mu}_L)$	stl	$\Gamma_{R_p}(\tilde{t}_1)$
sbl	$\Gamma_{R_p}(\tilde{b}_1)$	sntl	$\Gamma_{R_p}(\tilde{\nu}_\tau)$	stal	$\Gamma_{R_p}(\tilde{\tau}_1)$
sur	$\Gamma_{R_p}(\tilde{u}_R)$	sdr	$\Gamma_{R_p}(\tilde{d}_R)$	sner	-
ser	$\Gamma_{R_p}(\tilde{e}_R)$	scr	$\Gamma_{R_p}(\tilde{c}_R)$	ssr	$\Gamma_{R_p}(\tilde{s}_R)$
snmer	-	smr	$\Gamma_{R_p}(\tilde{\mu}_R)$	str	$\Gamma_{R_p}(\tilde{t}_2)$
sbr	$\Gamma_{R_p}(\tilde{b}_2)$	sntr	-	star	$\Gamma_{R_p}(\tilde{\tau}_2)$

Table 15: R-parity conserving widths ( $\Gamma_{R_p}$ ) of sparticles in GeV - block “COL4”. Does not include GMSB decays to the gravitino.



Variable	Description	Variable	Description	Variable	Description
rx01	$\Gamma_{\mathcal{R}_p}(\chi_1^0)$	rx02	$\Gamma_{\mathcal{R}_p}(\chi_2^0)$	rx03	$\Gamma_{\mathcal{R}_p}(\chi_3^0)$
rx04	$\Gamma_{\mathcal{R}_p}(\chi_4^0)$	rxp1	$\Gamma_{\mathcal{R}_p}(\chi_1^+)$	rxp2	$\Gamma_{\mathcal{R}_p}(\chi_2^+)$
rul	$\Gamma_{\mathcal{R}_p}(\tilde{u}_L)$	rdl	$\Gamma_{\mathcal{R}_p}(\tilde{d}_L)$	rnel	$\Gamma_{\mathcal{R}_p}(\tilde{\nu}_e)$
rel	$\Gamma_{\mathcal{R}_p}(\tilde{e}_L)$	rcl	$\Gamma_{\mathcal{R}_p}(\tilde{c}_L)$	rsl	$\Gamma_{\mathcal{R}_p}(\tilde{s}_L)$
rnmel	$\Gamma_{\mathcal{R}_p}(\tilde{\nu}_\mu)$	rml	$\Gamma_{\mathcal{R}_p}(\tilde{\mu}_L)$	rtl	$\Gamma_{\mathcal{R}_p}(\tilde{t}_1)$
rbl	$\Gamma_{\mathcal{R}_p}(\tilde{b}_1)$	rntl	$\Gamma_{\mathcal{R}_p}(\tilde{\nu}_\tau)$	rtal	$\Gamma_{\mathcal{R}_p}(\tilde{\tau}_1)$
rur	$\Gamma_{\mathcal{R}_p}(\tilde{u}_R)$	rdr	$\Gamma_{\mathcal{R}_p}(\tilde{d}_R)$	rner	-
rer	$\Gamma_{\mathcal{R}_p}(\tilde{e}_R)$	rcr	$\Gamma_{\mathcal{R}_p}(\tilde{c}_R)$	rsr	$\Gamma_{\mathcal{R}_p}(\tilde{s}_R)$
rnmer	-	rnr	$\Gamma_{\mathcal{R}_p}(\tilde{\mu}_R)$	rtr	$\Gamma_{\mathcal{R}_p}(\tilde{t}_2)$
rbr	$\Gamma_{\mathcal{R}_p}(\tilde{b}_2)$	rntr	-	rtar	$\Gamma_{\mathcal{R}_p}(\tilde{\tau}_2)$

Table 16: R-parity violating widths ( $\Gamma_{\mathcal{R}_p}$ ) of sparticles in GeV - block “COL5”.

Variable	Description	Variable	Description	Variable	Description
rx01	$\Gamma_{GMSB}(\chi_1^0)$	rx02	$\Gamma_{GMSB}(\chi_2^0)$	rx03	$\Gamma_{GMSB}(\chi_3^0)$
rx04	$\Gamma_{GMSB}(\chi_4^0)$	rxp1	$\Gamma_{GMSB}(\chi_1^+)$	rxp2	$\Gamma_{GMSB}(\chi_2^+)$
rul	$\Gamma_{GMSB}(\tilde{u}_L)$	rdl	$\Gamma_{GMSB}(\tilde{d}_L)$	rnel	$\Gamma_{GMSB}(\tilde{\nu}_e)$
rel	$\Gamma_{GMSB}(\tilde{e}_L)$	rcl	$\Gamma_{GMSB}(\tilde{c}_L)$	rsl	$\Gamma_{GMSB}(\tilde{s}_L)$
rnmel	$\Gamma_{GMSB}(\tilde{\nu}_\mu)$	rml	$\Gamma_{GMSB}(\tilde{\mu}_L)$	rtl	$\Gamma_{GMSB}(\tilde{t}_1)$
rbl	$\Gamma_{GMSB}(\tilde{b}_1)$	rntl	$\Gamma_{GMSB}(\tilde{\nu}_\tau)$	rtal	$\Gamma_{GMSB}(\tilde{\tau}_1)$
rur	$\Gamma_{GMSB}(\tilde{u}_R)$	rdr	$\Gamma_{GMSB}(\tilde{d}_R)$	rner	-
rer	$\Gamma_{GMSB}(\tilde{e}_R)$	rcr	$\Gamma_{GMSB}(\tilde{c}_R)$	rsr	$\Gamma_{GMSB}(\tilde{s}_R)$
rnmer	-	rnr	$\Gamma_{GMSB}(\tilde{\mu}_R)$	rtr	$\Gamma_{GMSB}(\tilde{t}_2)$
rbr	$\Gamma_{GMSB}(\tilde{b}_2)$	rntr	-	rtar	$\Gamma_{GMSB}(\tilde{\tau}_2)$

Table 17: GMSB widths ( $\Gamma_{R_{GMSB}}$ ) of sparticles in GeV - block “COL6”.

Variable	Description	Variable	Description	Variable	Description
rx01	$\Gamma(\chi_1^0)$	rx02	$\Gamma(\chi_2^0)$	rx03	$\Gamma(\chi_3^0)$
rx04	$\Gamma(\chi_4^0)$	rxp1	$\Gamma(\chi_1^+)$	rxp2	$\Gamma(\chi_2^+)$
rul	$\Gamma(\tilde{u}_L)$	rdl	$\Gamma(\tilde{d}_L)$	rnel	$\Gamma(\tilde{\nu}_e)$
rel	$\Gamma(\tilde{e}_L)$	rcl	$\Gamma(\tilde{c}_L)$	rsl	$\Gamma(\tilde{s}_L)$
rnmel	$\Gamma(\tilde{\nu}_\mu)$	rml	$\Gamma(\tilde{\mu}_L)$	rtl	$\Gamma(\tilde{t}_1)$
rbl	$\Gamma(\tilde{b}_1)$	rntl	$\Gamma(\tilde{\nu}_\tau)$	rtal	$\Gamma(\tilde{\tau}_1)$
rur	$\Gamma(\tilde{u}_R)$	rdr	$\Gamma(\tilde{d}_R)$	rner	-
rer	$\Gamma(\tilde{e}_R)$	rcr	$\Gamma(\tilde{c}_R)$	rsr	$\Gamma(\tilde{s}_R)$
rnmer	-	rnr	$\Gamma(\tilde{\mu}_R)$	rtr	$\Gamma(\tilde{t}_2)$
rbr	$\Gamma(\tilde{b}_2)$	rntr	-	rtar	$\Gamma(\tilde{\tau}_2)$

Table 18: Total widths ( $\Gamma = \Gamma_{\mathcal{R}_p} + \Gamma_{\mathcal{R}_p} + \Gamma_{R_{GMSB}}$ ) of sparticles in GeV - block “COL7”. This block is only present in the GMSB or  $\mathcal{R}_p$  modes.

Variable	Description	Variable	Description
brupx01	$d\Gamma(\tilde{u}_L \rightarrow u\chi_1^0)$	brupx02	$d\Gamma(\tilde{u}_L \rightarrow u\chi_2^0)$
brupxp1	$d\Gamma(\tilde{u}_L \rightarrow d\chi_1^+)$	brdownx01	$d\Gamma(\tilde{d}_L \rightarrow d\chi_1^0)$
brdownx02	$d\Gamma(\tilde{d}_L \rightarrow d\chi_2^0)$	brdownxp1	$d\Gamma(\tilde{d}_L \rightarrow u\chi_1^-)$
brneux01	$d\Gamma(\tilde{\nu}_e \rightarrow \nu_e\chi_1^0)$	brneux02	$d\Gamma(\tilde{\nu}_e \rightarrow \nu_e\chi_1^0)$
brneuxp1	$d\Gamma(\tilde{\nu}_e \rightarrow e^\mp\chi_1^\pm)$	brlax01	$d\Gamma(\tilde{e}_L \rightarrow e\chi_1^0)$
brlax02	$d\Gamma(\tilde{e}_L \rightarrow e\chi_2^0)$	brlaxp1	$d\Gamma(\tilde{e}_L \rightarrow \nu_e\chi_1^+)$
brstx01	$d\Gamma(\tilde{t}_1 \rightarrow c(ort)\chi_1^0)$	brstx02	$d\Gamma(\tilde{t}_1 \rightarrow c(ort)\chi_1^0)$
brstxp1	$d\Gamma(\tilde{t}_1 \rightarrow b\chi_1^+)$	brbotx01	$d\Gamma(\tilde{b}_1 \rightarrow b\chi_1^0)$
brbotx02	$d\Gamma(\tilde{b}_1 \rightarrow b\chi_2^0)$	brbotxp1	$d\Gamma(\tilde{b}_1 \rightarrow c(ort)\chi_2^-)$
brntx01	$d\Gamma(\tilde{\nu}_\tau \rightarrow \nu_\tau\chi_1^0)$	brntx02	$d\Gamma(\tilde{\nu}_\tau \rightarrow \nu_\tau\chi_2^0)$
brntxp1	$d\Gamma(\tilde{\nu}_\tau \rightarrow \tau^\mp\chi_1^\pm)$	brtaux01	$d\Gamma(\tilde{\tau}_1 \rightarrow \tau\chi_1^0)$
brtaux02	$d\Gamma(\tilde{\tau}_1 \rightarrow \tau\chi_1^0)$	brtauxp1	$d\Gamma(\tilde{\tau}_1 \rightarrow \nu_\tau\chi_1^+)$

Table 19: R-parity conserving partial widths in GeV - left handed sfermions. Block “COL8”.

Variable	Description	Variable	Description
brupx01r	$d\Gamma(\tilde{u}_R \rightarrow u\chi_1^0)$	brupx02r	$d\Gamma(\tilde{u}_R \rightarrow u\chi_2^0)$
brupxp1r	$d\Gamma(\tilde{u}_R \rightarrow d\chi_1^+)$	brdownx01r	$d\Gamma(\tilde{d}_R \rightarrow d\chi_1^0)$
brdownx02r	$d\Gamma(\tilde{d}_R \rightarrow d\chi_2^0)$	brdownxp1r	$d\Gamma(\tilde{d}_R \rightarrow u\chi_1^-)$
brlax01r	$d\Gamma(\tilde{e}_R \rightarrow e\chi_1^0)$	brlax02r	$d\Gamma(\tilde{e}_R \rightarrow e\chi_2^0)$
brlaxp1r	$d\Gamma(\tilde{e}_R \rightarrow \nu_e\chi_1^+)$	brstx01r	$d\Gamma(\tilde{t}_2 \rightarrow c(ort)\chi_1^0)$
brstx02r	$d\Gamma(\tilde{t}_2 \rightarrow c(ort)\chi_1^0)$	brstxp1r	$d\Gamma(\tilde{t}_2 \rightarrow b\chi_1^+)$
brbotx01r	$d\Gamma(\tilde{b}_2 \rightarrow b\chi_1^0)$	brbotx02r	$d\Gamma(\tilde{b}_2 \rightarrow b\chi_2^0)$
brbotxp1r	$d\Gamma(\tilde{b}_2 \rightarrow c(ort)\chi_2^-)$	brtaux01r	$d\Gamma(\tilde{\tau}_2 \rightarrow \tau\chi_1^0)$
brtaux02r	$d\Gamma(\tilde{\tau}_2 \rightarrow \tau\chi_1^0)$	brtauxp1r	$d\Gamma(\tilde{\tau}_2 \rightarrow \nu_\tau\chi_1^+)$

Table 20: R-parity conserving partial widths in GeV - right handed sfermions. Block “COL8”.

Variable	Description	Variable	Description
brx2a	$d\Gamma(\chi_2^0 \rightarrow q\bar{q}\chi_1^0)$	brx2b	$d\Gamma(\chi_2^0 \rightarrow e^+e^-\chi_1^0)$
brx2c	$d\Gamma(\chi_2^0 \rightarrow \mu^+\mu^-\chi_1^0)$	brx2d	$d\Gamma(\chi_2^0 \rightarrow \tau^+\tau^-\chi_1^0)$
brx2e	$d\Gamma(\chi_2^0 \rightarrow \nu\bar{\nu}\chi_1^0)$	brx2f	$d\Gamma(\chi_2^0 \rightarrow \gamma\chi_1^0)$
brx2g	$d\Gamma(\chi_2^0 \rightarrow h(or H)\chi_1^0)$	brx2h	$d\Gamma(\chi_2^0 \rightarrow H^\mp\chi_1^\pm)$
brxp1a	$d\Gamma(\chi_1^+ \rightarrow qq'\chi_1^0)$	brxp1b	$d\Gamma(\chi_1^+ \rightarrow e\nu\chi_1^0)$
brxp1c	$d\Gamma(\chi_1^+ \rightarrow \mu\nu\chi_1^0)$	brxp1d	$d\Gamma(\chi_1^+ \rightarrow \tau\nu\chi_1^0)$
brxp1e	$d\Gamma(\chi_1^+ \rightarrow H^+\chi_1^0)$	brxp1f	-
brxp1g	-	brxp1h	-

Table 21: R-parity conserving partial widths in GeV - Charginos and Neutralinos. Block “COL9”.

Variable	Description	Variable	Description	Variable	Description
ex1x1	$\epsilon(\chi_1^0 \chi_1^0)$	ex1x2	$\epsilon(\chi_1^0 \chi_2^0)$	ex2x2	$\epsilon(\chi_2^0 \chi_2^0)$
ex1x3	$\epsilon(\chi_1^0 \chi_3^0)$	ex2x3	$\epsilon(\chi_2^0 \chi_3^0)$	ex3x3	$\epsilon(\chi_3^0 \chi_3^0)$
ex1x4	$\epsilon(\chi_1^0 \chi_4^0)$	ex2x4	$\epsilon(\chi_2^0 \chi_4^0)$	ex3x4	$\epsilon(\chi_3^0 \chi_4^0)$
ex4x4	$\epsilon(\chi_4^0 \chi_4^0)$	ex1x1p	$\epsilon(\chi_1^+ \chi_1^+)$	ex1x2p	$\epsilon(\chi_1^+ \chi_2^+)$
ex2x2p	$\epsilon(\chi_2^+ \chi_2^+)$	enue	$\epsilon(\tilde{\nu}_e \tilde{\nu}_e)$	enutot	$\epsilon(\tilde{\nu}_e \tilde{\nu}_e + \tilde{\nu}_\mu \tilde{\nu}_\mu + \tilde{\nu}_\tau \tilde{\nu}_\tau)$
esel	$\epsilon(\tilde{e}_L \tilde{e}_L)$	eser	$\epsilon(\tilde{e}_R \tilde{e}_R)$	eselser	$\epsilon(\tilde{e}_L \tilde{e}_R)$
emul	$\epsilon(\tilde{\mu}_L \tilde{\mu}_L)$	emur	$\epsilon(\tilde{\mu}_R \tilde{\mu}_R)$	etau1	$\epsilon(\tilde{\tau}_1 \tilde{\tau}_1)$
etau2	$\epsilon(\tilde{\tau}_2 \tilde{\tau}_2)$	ebt1	$\epsilon(\tilde{b}_1 \tilde{b}_1)$	ebt2	$\epsilon(\tilde{b}_2 \tilde{b}_2)$
etp1	$\epsilon(\tilde{t}_1 \tilde{t}_1)$	etp2	$\epsilon(\tilde{t}_2 \tilde{t}_2)$	eupl	$\epsilon(\tilde{u}_L \tilde{u}_L)$
edowl	$\epsilon(\tilde{d}_L \tilde{d}_L)$	echal	$\epsilon(\tilde{c}_L \tilde{c}_L)$	estl	$\epsilon(\tilde{s}_L \tilde{s}_L)$
eupr	$\epsilon(\tilde{u}_R \tilde{u}_R)$	edowr	$\epsilon(\tilde{d}_R \tilde{d}_R)$	echar	$\epsilon(\tilde{c}_R \tilde{c}_R)$
estr	$\epsilon(\tilde{s}_R \tilde{s}_R)$	egx1	$\epsilon(\chi_1^0 \tilde{G})$	egx2	$\epsilon(\chi_2^0 \tilde{G})$
egx3	$\epsilon(\chi_3^0 \tilde{G})$	egx4	$\epsilon(\chi_4^0 \tilde{G})$	erpvx1	$\epsilon(\chi_1^0 \nu)$
erpvx2	$\epsilon(\chi_2^0 \nu)$	erpvx3	$\epsilon(\chi_3^0 \nu)$	erpvx4	$\epsilon(\chi_4^0 \nu)$
erpvx1p	$\epsilon(\chi_1^+ l^-)$	erpvx2p	$\epsilon(\chi_2^+ l^-)$	ezh1	$\epsilon(hZ)$
ezh2	$\epsilon(HZ)$	eah1	$\epsilon(hA)$	eah2	$\epsilon(HA)$
ehphp	$\epsilon(H^+ H^-)$				

Table 22: Efficiencies (calculated in routine USER) for the various signals - block “COL10”.

## F Test Run Input

```
**** SUGRA mode
MODES 1
M 80.
mu -50.
m0 100.
tanb 1.41
****
ECM 183.
* initial state radiation ON
ISR 1
* list events
DEBUG 1
* write o/p to fortran file unit 12
GENER 1
LUWRIT TRUE
**** generate one chargino pair event
WINO TRUE
SUSEVENTS 1.
END
```

## G Test Run Output

### G.1 The susygen.dat file

```
INPUTS:
M      =    80.000    mu      =   -50.000
m0     =   100.000    TANB    =    1.410
At     =    0.000    Ab      =    0.000 Atau =    0.000
Ecm    =   183.000    EVENTS  =    1.000 RAD CORR=    1
```

#### Sparticle masses

SUPR	253.	SUPL	260.
SDNR	253.	SDNL	263.
SELR	110.	SELL	125.
SNU	117.		
STPL	312.	STPR	307.
SBTL	263.	SBTR	253.
STAL	125.	STAR	110.

M1 = 40.107 M2 = 80.000

NEUTRALINO m, CP, ph/zi/ha/hb 1	=	45.0	1.	0.755	-0.196	-0.083	-0.620
NEUTRALINO m, CP, ph/zi/ha/hb 2	=	49.7	1.	0.625	0.014	-0.118	0.772
NEUTRALINO m, CP, ph/zi/ha/hb 3	=	98.9	-1.	0.054	-0.476	0.872	0.099
NEUTRALINO m, CP, ph/zi/ha/hb 4	=	124.4	1.	0.192	0.857	0.467	-0.100

CHARGINO MASSES	=	82.205	122.500
CHARGINO ETA	=	1.000	1.000

U matrix	WINO	HIGGSINO
W1SS+	-0.076	0.997
W2SS+	0.997	0.076

V matrix	WINO	HIGGSINO
W1SS-	0.722	-0.692
W2SS-	0.692	0.722

#### HIGGS masses

Light CP-even Higgs	=	56.372
Heavy CP-even Higgs	=	313.893
CP-odd Higgs	=	300.000
Charged Higgs	=	310.070
sin(a-b)	=	-0.613
cos(a-b)	=	0.790

PARENT -->	DAUGHTERS	WIDTH (eV)	BRANCHING RATIO
------------	-----------	------------	-----------------

MASS of Z1SS	=	44.9614410400391	GeV
Z2SS --> Z1SS	UP UB	0.019	2.12
Z2SS --> Z1SS	DN DB	0.024	2.73
Z2SS --> Z1SS	NUE ANUE	0.011	1.21
Z2SS --> Z1SS	CH CB	0.002	0.25
Z2SS --> Z1SS	ST SB	0.022	2.48
Z2SS --> Z1SS	NUM ANUM	0.011	1.21
Z2SS --> Z1SS	NUT ANUT	0.011	1.21
Z2SS --> Z1SS	GAMMA	0.785	88.79

MASS of Z2SS	=	49.7181472778320	GeV
Total WIDTH of Z2SS	=	8.838237113852746E-010	GeV
Lifetime	=	2.2289512E-05	cm

Z3SS --> Z1SS	UP UB	7815.816	4.86
Z3SS --> Z1SS	DN DB	10375.482	6.45
Z3SS --> Z1SS	NUE ANUE	6575.981	4.09
Z3SS --> Z1SS	E- E+	3426.354	2.13
Z3SS --> Z1SS	CH CB	7759.725	4.82
Z3SS --> Z1SS	ST SB	10372.120	6.44
Z3SS --> Z1SS	NUM ANUM	6575.981	4.09
Z3SS --> Z1SS	MU- MU+	3426.271	2.13
Z3SS --> Z1SS	BT BB	9638.576	5.99
Z3SS --> Z1SS	NUT ANUT	6575.981	4.09
Z3SS --> Z1SS	TAU- TAU+	3393.080	2.11
Z3SS --> Z1SS	GAMMA	16.500	0.01
Z3SS --> Z2SS	UP UB	9585.074	5.95
Z3SS --> Z2SS	DN DB	11596.827	7.20
Z3SS --> Z2SS	NUE ANUE	5487.067	3.41
Z3SS --> Z2SS	E- E+	4263.929	2.65
Z3SS --> Z2SS	CH CB	9491.563	5.90
Z3SS --> Z2SS	ST SB	11592.267	7.20
Z3SS --> Z2SS	NUM ANUM	5487.067	3.41
Z3SS --> Z2SS	MU- MU+	4263.800	2.65
Z3SS --> Z2SS	BT BB	10586.754	6.58

Z3SS	-->	Z2SS	NUT	ANUT	5487.067	3.41
Z3SS	-->	Z2SS	TAU-	TAU+	4210.220	2.62
Z3SS	-->	Z2SS	GAMMA		958.936	0.60
Z3SS	-->	W1SS+	DN	UB	549.331	0.34
Z3SS	-->	W1SS+	E-	ANUE	318.880	0.20
Z3SS	-->	W1SS+	ST	CB	515.701	0.32
Z3SS	-->	W1SS+	MU-	ANUM	318.860	0.20
Z3SS	-->	W1SS+	TAU-	ANUT	298.372	0.19

MASS of Z3SS = 98.9230117797852 GeV  
 Total WIDTH of Z3SS = 1.609635813320035E-004 GeV  
 Lifetime = 1.2238793E-10 cm

Z4SS	-->	Z1SS	UP	UB	64341.051	0.20
Z4SS	-->	Z1SS	DN	DB	71851.289	0.23
Z4SS	-->	Z1SS	NUE	ANUE	799706.625	2.53
Z4SS	-->	Z1SS	E-	E+	1257176.125	3.98
Z4SS	-->	Z1SS	CH	CB	64144.719	0.20
Z4SS	-->	Z1SS	ST	SB	71837.734	0.23
Z4SS	-->	Z1SS	NUM	ANUM	799710.813	2.53
Z4SS	-->	Z1SS	MU-	MU+	1257128.750	3.98
Z4SS	-->	Z1SS	BT	BB	70013.922	0.22
Z4SS	-->	Z1SS	NUT	ANUT	800902.125	2.54
Z4SS	-->	Z1SS	TAU-	TAU+	1239106.500	3.93
Z4SS	-->	Z1SS	HOL		11142074.000	35.31
Z4SS	-->	Z2SS	UP	UB	70878.781	0.22
Z4SS	-->	Z2SS	DN	DB	113081.391	0.36
Z4SS	-->	Z2SS	NUE	ANUE	47392.527	0.15
Z4SS	-->	Z2SS	E-	E+	651443.563	2.06
Z4SS	-->	Z2SS	CH	CB	70611.727	0.22
Z4SS	-->	Z2SS	ST	SB	113055.344	0.36
Z4SS	-->	Z2SS	NUM	ANUM	47392.547	0.15
Z4SS	-->	Z2SS	MU-	MU+	651432.125	2.06
Z4SS	-->	Z2SS	BT	BB	109480.492	0.35
Z4SS	-->	Z2SS	NUT	ANUT	47398.039	0.15
Z4SS	-->	Z2SS	TAU-	TAU+	647318.063	2.05
Z4SS	-->	Z2SS	HOL		1357764.000	4.30
Z4SS	-->	Z3SS	NUE	ANUE	500639.094	1.59
Z4SS	-->	Z3SS	E-	E+	8530.695	0.03
Z4SS	-->	Z3SS	NUM	ANUM	500641.719	1.59
Z4SS	-->	Z3SS	MU-	MU+	8529.966	0.03
Z4SS	-->	Z3SS	NUT	ANUT	501390.094	1.59
Z4SS	-->	Z3SS	TAU-	TAU+	8321.920	0.03
Z4SS	-->	W1SS+	DN	UB	26603.908	0.08
Z4SS	-->	W1SS+	E-	ANUE	2805715.750	8.89
Z4SS	-->	W1SS+	ST	CB	26414.109	0.08
Z4SS	-->	W1SS+	MU-	ANUM	2805695.500	8.89
Z4SS	-->	W1SS+	TAU-	ANUT	2799321.750	8.87

MASS of Z4SS = 124.350257873535 GeV  
 Total WIDTH of Z4SS = 3.155728429046366E-002 GeV  
 Lifetime = 6.2426160E-13 cm

W1SS+	-->	Z1SS	UP	DB	11165.424	20.37
W1SS+	-->	Z1SS	NUE	E+	3578.382	6.53
W1SS+	-->	Z1SS	CH	SB	11047.252	20.15
W1SS+	-->	Z1SS	NUM	MU+	3578.319	6.53
W1SS+	-->	Z1SS	NUT	TAU+	3548.031	6.47
W1SS+	-->	Z2SS	UP	DB	7352.349	13.41

W1SS+	-->	Z2SS	NUE	E+	2441.424	4.45
W1SS+	-->	Z2SS	CH	SB	7255.331	13.23
W1SS+	-->	Z2SS	NUM	MU+	2441.417	4.45
W1SS+	-->	Z2SS	NUT	TAU+	2417.434	4.41

MASS of W1SS+	=	82.2054044085650	GeV
Total WIDTH of W1SS+	=	5.482536228723776E-005	GeV
Lifetime	=	3.5932274E-10	cm

W2SS+	-->	Z1SS	UP	DB	389890.656	7.89
W2SS+	-->	Z1SS	NUE	E+	376353.063	7.62
W2SS+	-->	Z1SS	CH	SB	389994.125	7.89
W2SS+	-->	Z1SS	NUM	MU+	376345.625	7.62
W2SS+	-->	Z1SS	NUT	TAU+	365778.000	7.40
W2SS+	-->	Z2SS	UP	DB	626844.563	12.69
W2SS+	-->	Z2SS	NUE	E+	381795.750	7.73
W2SS+	-->	Z2SS	CH	SB	625884.000	12.67
W2SS+	-->	Z2SS	NUM	MU+	381794.438	7.73
W2SS+	-->	Z2SS	NUT	TAU+	381132.250	7.71
W2SS+	-->	Z3SS	UP	DB	1306.987	0.03
W2SS+	-->	Z3SS	NUE	E+	154496.859	3.13
W2SS+	-->	Z3SS	CH	SB	1267.973	0.03
W2SS+	-->	Z3SS	NUM	MU+	154476.875	3.13
W2SS+	-->	Z3SS	NUT	TAU+	141892.547	2.87
W2SS+	-->	W1SS+	UP	UB	2861.109	0.06
W2SS+	-->	W1SS+	DN	DB	5163.812	0.10
W2SS+	-->	W1SS+	NUE	ANUE	41784.742	0.85
W2SS+	-->	W1SS+	E-	E+	15585.073	0.32
W2SS+	-->	W1SS+	CH	CB	2810.073	0.06
W2SS+	-->	W1SS+	ST	SB	5158.582	0.10
W2SS+	-->	W1SS+	NUM	ANUM	41784.945	0.85
W2SS+	-->	W1SS+	MU-	MU+	15583.285	0.32
W2SS+	-->	W1SS+	BT	BB	4413.938	0.09
W2SS+	-->	W1SS+	NUT	ANUT	41842.730	0.85
W2SS+	-->	W1SS+	TAU-	TAU+	14907.641	0.30

MASS of W2SS+	=	122.500414227970	GeV
Total WIDTH of W2SS+	=	4.941149627879395E-003	GeV
Lifetime	=	3.9869262E-12	cm

MASS of UPL	=	259.504386750604	GeV
-------------	---	------------------	-----

MASS of DNL	=	263.370394294766	GeV
-------------	---	------------------	-----

NUEL	-->	Z1SS	NUE	17929614.000	11.16
NUEL	-->	Z2SS	NUE	88574.359	0.06
NUEL	-->	Z3SS	NUE	11599536.000	7.22
NUEL	-->	W1SS+	E-	131070248.000	81.57

MASS of NUEL	=	116.793041222755	GeV
Total WIDTH of NUEL	=	0.160687973351000	GeV
Lifetime	=	1.2259785E-13	cm

EL-	-->	Z1SS	E-	147906416.000	49.85
EL-	-->	Z2SS	E-	140011936.000	47.19
EL-	-->	Z3SS	E-	4365978.000	1.47
EL-	-->	Z4SS	E-	87047.195	0.03
EL-	-->	W1SS-	NUE	1985265.250	0.67
EL-	-->	W2SS-	NUE	2332605.750	0.79

MASS of EL-	=	125.486749674947	GeV	
Total WIDTH of EL-	=	0.296689237161868	GeV	
Lifetime	=	6.6399441E-14 cm		
MASS of CHL	=	259.504386750604	GeV	
MASS of STL	=	263.370394294766	GeV	
NUML --> Z1SS	NUM	17929614.000		11.16
NUML --> Z2SS	NUM	88574.359		0.06
NUML --> Z3SS	NUM	11599536.000		7.22
NUML --> W1SS+	MU-	131069416.000		81.57
MASS of NUML	=	116.793041222755	GeV	
Total WIDTH of NUML	=	0.160687141212113	GeV	
Lifetime	=	1.2259848E-13 cm		
MUL- --> Z1SS	MU-	147906352.000		49.85
MUL- --> Z2SS	MU-	140012720.000		47.19
MUL- --> Z3SS	MU-	4365900.500		1.47
MUL- --> Z4SS	MU-	86681.125		0.03
MUL- --> W1SS-	NUM	1985265.250		0.67
MUL- --> W2SS-	NUM	2332605.750		0.79
MASS of MUL-	=	125.486749674947	GeV	
Total WIDTH of MUL-	=	0.296689524561566	GeV	
Lifetime	=	6.6399380E-14 cm		
MASS of BT1	=	263.417851693807	GeV	
MASS of TP1	=	312.439636958576	GeV	
NUTL --> Z1SS	NUT	17929614.000		11.17
NUTL --> Z2SS	NUT	88574.359		0.06
NUTL --> Z3SS	NUT	11599536.000		7.23
NUTL --> W1SS+	TAU-	130831880.000		81.54
MASS of NUTL	=	116.793041222755	GeV	
Total WIDTH of NUTL	=	0.160449605025549	GeV	
Lifetime	=	1.2277999E-13 cm		
TAU1- --> Z1SS	TAU-	147912640.000		49.83
TAU1- --> Z2SS	TAU-	140262848.000		47.25
TAU1- --> Z3SS	TAU-	4347101.000		1.46
TAU1- --> W1SS-	NUT	1986060.125		0.67
TAU1- --> W2SS-	NUT	2351768.000		0.79
MASS of TAU1-	=	125.499288741710	GeV	
Total WIDTH of TAU1-	=	0.296860418547054	GeV	
Lifetime	=	6.6361155E-14 cm		
MASS of UPR	=	253.087070455429	GeV	
MASS of DNR	=	253.391977765737	GeV	
ER- --> Z1SS	E-	221465200.000		67.88
ER- --> Z2SS	E-	103275600.000		31.65
ER- --> Z3SS	E-	1522374.125		0.47



MASS of ER-	=	109.855352062128	GeV
Total WIDTH of ER-	=	0.326263181300843	GeV
Lifetime	=	6.0380703E-14 cm	
MASS of CHR	=	253.087070455429	GeV
MASS of STR	=	253.391977765737	GeV
MUR- --> Z1SS MU-		221465760.000	67.88
MUR- --> Z2SS MU-		103275296.000	31.65
MUR- --> Z3SS MU-		1522204.250	0.47
MASS of MUR-	=	109.855352062128	GeV
Total WIDTH of MUR-	=	0.326263714477010	GeV
Lifetime	=	6.0380601E-14 cm	
MASS of TP2	=	307.130371718121	GeV
MASS of BT2	=	253.439037459913	GeV
TAU2- --> Z1SS TAU-		221675248.000	67.89
TAU2- --> Z2SS TAU-		103215376.000	31.61
TAU2- --> Z3SS TAU-		1477561.500	0.45
TAU2- --> W1SS- NUT		131231.641	0.04
MASS of TAU2-	=	109.869716964501	GeV
Total WIDTH of TAU2-	=	0.326499416297990	GeV
Lifetime	=	6.0337016E-14 cm	
MASS of GLSS	=	148.387594191548	GeV
MASS of HOL	=	56.3720788464574	GeV
MASS of HOH	=	313.892691024644	GeV
MASS of A0	=	300.000000000000	GeV
MASS of H+	=	310.070287501751	GeV
MASS of TP	=	174.000000000000	GeV

Cross section of W1SS+ W1SS- = 0.89911E+00 pb

## G.2 The susygen.log file

### Event listing (summary)

I	particle/jet KS	KF orig	p_x	p_y	p_z	E	m	
1	!E--!	21	11	0	0.000	0.000	91.500	0.000
2	!E--!	21	-11	0	0.000	0.000	-91.500	0.000
3	GAMMA	1	22	0	0.000	0.000	-0.964	0.964
4	(SusyProd0)	11	79	0	0.000	0.000	0.964	182.036
5	(W1SS++)	11	75	4	-17.668	-31.556	15.259	91.096
6	(W1SS-)	11	77	4	17.668	31.556	-14.295	90.940
7	NUT	1	16	5	5.178	-0.308	-7.449	9.077

8	(TAU-+)	11	-15	5	1.541	4.919	14.326	15.328	1.777
9	(Z2SS0)	11	72	5	-24.386	-36.167	8.383	66.691	49.718
10	NUT~	1	-16	6	16.947	16.397	1.743	23.645	0.000
11	(TAU--)	11	15	6	10.948	-2.815	-2.115	11.637	1.777
12	(Z2SS0)	11	72	6	-10.227	17.974	-13.923	55.657	49.718
13	GAMMA	1	22	9	-3.387	-8.227	3.401	9.525	0.000
14	Z1SS0	1	71	9	-20.999	-27.940	4.981	57.166	44.961
15	GAMMA	1	22	12	-4.034	-1.489	-2.487	4.967	0.000
16	Z1SS0	1	71	12	-6.193	19.463	-11.435	50.690	44.961
17	NUT~	1	-16	8	-0.015	1.559	3.381	3.723	0.000
18	pi+	1	211	8	1.160	1.789	5.627	6.019	0.140
19	(eta)	11	221	8	0.396	1.571	5.318	5.587	0.548
20	NUT	1	16	11	3.007	-0.958	0.086	3.157	0.000
21	(rho-)	11	-213	11	7.941	-1.857	-2.202	8.480	0.741
22	GAMMA	1	22	19	0.076	1.008	3.876	4.006	0.000
23	GAMMA	1	22	19	0.319	0.563	1.442	1.581	0.000
24	pi-	1	-211	21	0.341	-0.086	-0.036	0.380	0.140
25	(pi0)	11	111	21	7.600	-1.771	-2.165	8.099	0.135
26	GAMMA	1	22	25	0.863	-0.245	-0.241	0.929	0.000
27	GAMMA	1	22	25	6.736	-1.526	-1.924	7.170	0.000
	sum:	0.00			0.000	0.000	0.000	183.000	183.000

Susygen has now finished ... Bye